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PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF STREAMS IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

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UPLANDS FIELD RESEARCH LABORATORY
GREAT SMOKY MOUNTAINS NATIONAL PARK
TWIN CREEKS AREA
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PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF STREAMS IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Research/Resources Management Report No. 47

June 1981

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ABSTRACT

Water samples from streams in the Great Smoky Mountains National Park were analyzed for 16 physical, chemical, and bacteriological water quality parameters. Bacterial densities, pH, alkalinity, turbidity, and concentrations of Na, K, and Si were found to be higher in the low elevations than high. Nitrate concentrations were higher in the high elevation samples, and watersheds which had been logged prior to the establishment of the park had significantly lower streamwater nitrate concentrations than unlogged watersheds in similar elevations. Bedrock geology was found to influence pH, alkalinity, conductivity, hardness, and concentrations of Na, K, Ca, Mg, and Si. Seasonal variation in water quality and the reaction of streamwater quality to storms are also described.

Stream channel characteristics were also analyzed in some streams. The size distribution of substrate was found to depend significantly on stream gradient, with larger sizes predominating on steeper streams and smaller sizes on less steep streams. Streams in previously logged areas had significantly less large woody debris than those in virgin areas.

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We would like to thank all those who helped with the collection and laboratory analysis of water samples, particularly Debbie Hurley, Karen Buzby, Karl Zimmerer, Jim Pitrak, and Peter Cornelius. Dan Stoneburner provided the atomic absorption elemental analysis. Wayne Williams permitted the use of his chemical laboratory for the project.

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INTRODUCTION

The Great Smoky Mountains National Park (GRSM) is located on the Tennessee-North Carolina border. Within the boundaries of the park are approximately 2,090 km^2 of predominantly forested mountains, ranging in elevation from 270 to 2,025 m. The vegetation of the area is known for its diversity, with forest types ranging from virgin areas of hardwood, hemlock, and spruce-fir forests to areas logged, burned, or farmed before the establishment of the park. Other areas are still maintained as open fields for historic purposes. Further complexity is added by variation along moisture and elevation gradients (Whittaker 1956). The geology of the park is also varied. Although most of the bedrock is sedimentary in origin, it has been subject to folding, faulting, and low-grade metamorphism. Seventeen geological formations in five major groups are recognized in the park (King et al. 1968).

With only a few minor exceptions, no streams in GRSM drain areas outside the park. Because of this, the streams are not affected directly by nearby agricultural and commercial developments. Nevertheless, threats to park water quality do exist in the form of airborne pollutants from outside the park (Cogbill 1976; Wiersma et al. 1978; and Larson et al. 1978), management of historical areas within the park (Mathews 1978), development of new park facilities (Herrmann et al. 1976; Huckabee et al. 1975), exotic animals (Singer, unpublished data), and visitor use (Bratton et al. 1979; Larson and Hammitt 1981).

In order to recognize deterioration in water quality if it does occur, identify sensitive areas, and assess the potential for adverse impacts, it is necessary to have a fundamental understanding of the patterns and extent of existing variations in water quality. Future aquatic studies will depend upon a basic knowledge of which streams are similar in water quality and which are different so that representative streams can be investigated. This one-year study was intended to fill this gap by providing background data on water quality and identifying some of the important factors determining the water quality of park streams.

METHODS

One hundred ten study streams were sampled 4 times, at intervals of approximately 3 months, starting in October 1977 and ending in September 1978. Samples were taken from the base of most of the 28 major drainages in the park. Extensive sampling was conducted within 8 of the drainages by collecting samples from tributaries at a wide range of elevations and from the main streams at several elevations from the headwaters to the park boundary. Thirty other locations were sampled one or two times. In addition, samples were collected daily from LeConte Creek and one of its low elevation tributaries, Scratch Britches Creek, at an elevation of 590 m, to assess patterns of day to day variation. Twenty-four hour diel studies, with samples collected every 3 hours, were conducted on 8 streams under varying weather conditions. Sample locations are shown in Figure 1.

Temperature and discharge measurements were made in the field, and samples were collected in sterile 1-ℓ polyethylene bottles for laboratory analysis. Separate 125-ml samples for nitrate determinations were collected and preserved with phenylmercuric acetate (American Public Health Association 1971). Laboratory analyses were conducted within

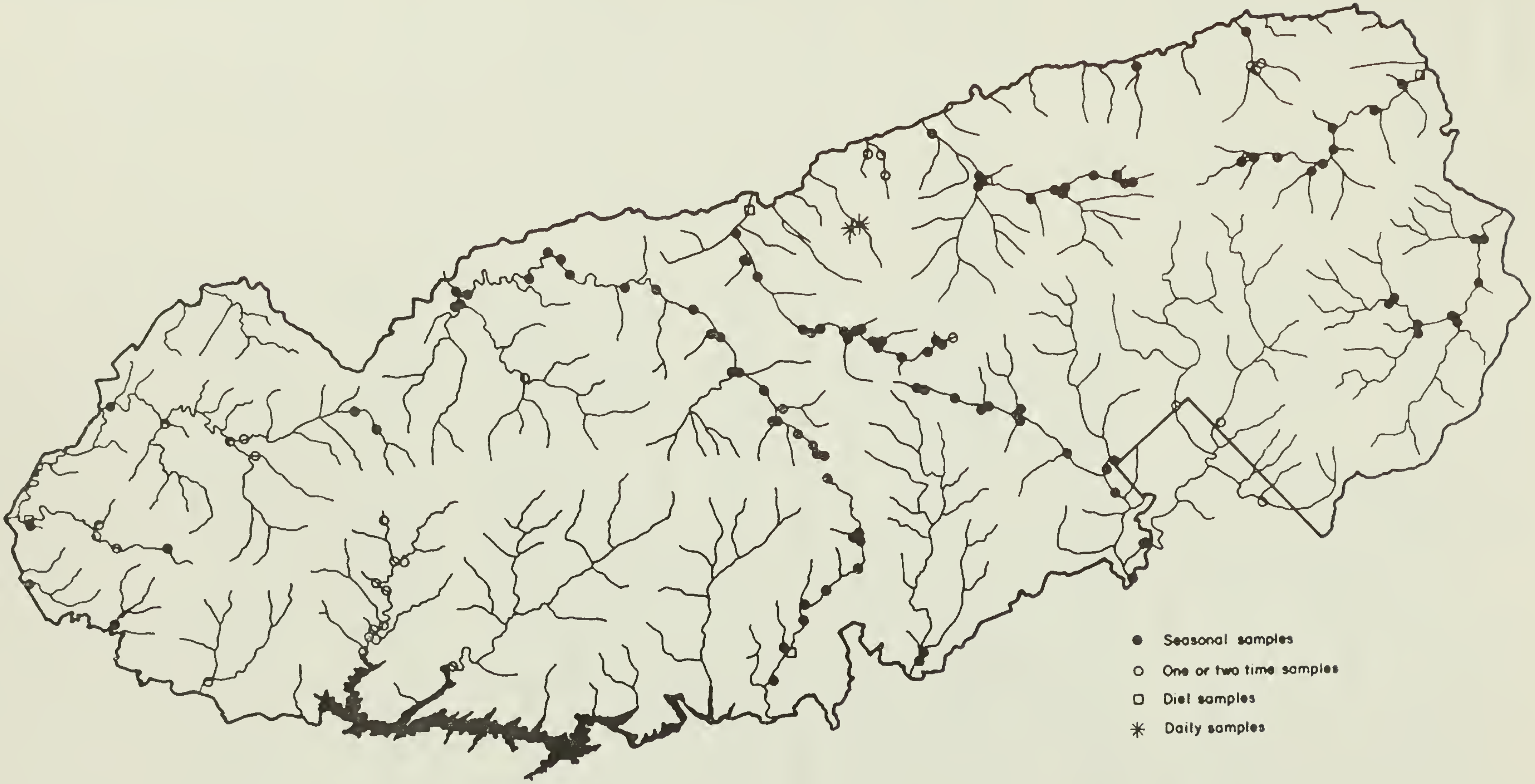

Figure 1. Location of sampling stations in Great Smoky Mountains National Park.

24 hours after collection. Field and laboratory methods are summarized in Table 1. Eighty samples, collected in September 1978, were preserved with 1 ml nitric acid per 100 ml and analyzed for Ca, Mg, Na, K, and Si, using atomic absorption spectrophotometry.

For each sample location, the drainage basin was described as follows: (1) The area of the watershed between each 1,000-ft contour line was measured from topographic maps using a planimeter. A weighted mean elevation for the watershed was then computed according to the formula:

$$\text{Mean elevation} = \frac{1}{A_T}\left[1000\ (A_{0-1}) + 1500\ (A_{1-2}) + 2500\ (A_{2-3}) \ldots + 5500\ (A_{5-6}) + 6200\ (A_{6-7})\right]$$

where A_T is the total area of the watershed upstream from the sample location, A_{0-1} is the area of the watershed below 1000 ft, A_{1-2} is the area between 1000 and 2000 ft, etc.

(2) The percentage of each watershed which had been logged or farmed prior to the establishment of the park was estimated from records in the park archives (Lambert 1958).

(3) The percentage of each watershed underlain by each of five major bedrock types was estimated from the geologic map of the park (King et al. 1968). A brief description of geological groups used in this study is presented in Table 2. Although the Anakeesta formation is a part of the Great Smoky Group, it was separated for purposes of this study. Formations present in each group are listed in Table 3.

SAS procedures were used for statistical analysis of the data (Barr et al. 1976).

Substrate composition was assessed at stations on 6 major streams and some of their tributaries. Stations were placed at 1-km intervals from the headwaters to the park boundary. At each station the substrate was inspected at one-meter intervals along line transects across the stream. The length of the transects varied with the width of the stream. Transects were spaced at 10-meter intervals up the stream, and enough transects were used to give a minimum of 50 meters total length at each station. All transects were completed the full width of the stream.

Table 1. Methods used for water analysis.

Parameter	Method/Equipment
pH	Orion Model 407A Specific Ion/pH meter
Conductivity	YSI Model 33 Salinity-Conductivity-Temperature meter
Dissolved Oxygen	YSI Model 54A Dissolved Oxygen meter
Alkalinity	Titration of 50 ml sample with .02 N $H_2 SO_4$ to Bromcresal Green - Methyl Red endpoint (Amer. Public Health Assoc. 1971)
Hardness	pH adjusted to 10.0. Titration of 50-ml sample with .02 N EDTA to Eriochrome Black T endpoint (Amer. Public Health Assoc. 1971)
Turbidity	HF Instruments Model DRT-100 Nephelometric turbidimeter
Temperature	Field instrument with laboratory thermometer
Discharge	Current and depth measurements using Gurley Pygmy Current meter
Nitrate	Orion 407A Specific Ion meter with Nitrate electrode
Fecal Streptococcus	Filtration on Millipore type HC filter and incubation for 48 hr at 35°C on Difco KF streptococcus agar. 20-100 ml filtered, depending on expected density (Amer. Public Health Assoc. 1971)
Fecal Coliform	Filtration on Millipore-type HC filter and incubation for 24 hr at 44.5 C on Difco M-FC Broth. 250 ml samples were filtered. (Amer. Public Health Assoc. 1971)
Total Coliform	Filtration on Millipore-type HC filter, and incubation for 24 hr at 35 C on Difco M-Endo Broth. 5-100 ml were filtered, depending on expected densities. (Amer. Health Assoc. 1971)

Table 2. A summary of characteristics of the five geologic groups discussed in the text (compiled from King et al. 1968)

Group	Major rock types	Structural characteristics	Most significant minerals	Distribution in GRSM
Great Smoky Group	sandstone	massive, thickbedded low porosity	quartz potassic feldspar	all elevations 60% of park
Anakeesta	slate, phyllite, schist	discontinuous patches, easily fractured	clay minerals, sulfides	high elevation 8% of park
Walden Creek Group	shale, siltstone, conglomerate, limestone, dolomite	weak, broken by intense folding and faulting	feldspars, clay minerals, carbonates	low elevation 10% of park
Snowbird Group	shale, siltstone, sandstone, quartzite	highly variable, structurally weak	feldspars, quartz, clay minerals	low elevation 20% of park
Knox Group	limestone	extremely porous	carbonates	low elevation 2% of park

Table 3. Geological formations included in the groups used in this study.[1]

Great Smoky Group

Elkmont sandstone
Thunderhead sandstone
Unnamed sandstone
Unmapped areas of the park

NOTE: Anakeesta formation treated separately.

Anakeesta Formation

Includes no other types.

Snowbird Group

Wading Branch formation
Long Arm quartzite
Roaring Fork sandstone
Pigeon siltstone
Metcalf phyllite
Cades Cove sandstone
Rich Butt sandstone

Walden Creek Group

Only Wilhite formation found in the park.

Knox Group

Limestones and dolomites; not mapped individually

---

[1] Based upon King et al. 1968

Substrate was grouped into eight classes: sand, gravel, rocks 3-10 cm in their largest dimension, 10-30 cm, 30-100 cm, 1-3 m, greater than 3 m, and bedrock.

In addition, estimates of the volume of large woody debris were made at each substrate station. For each transect across the stream, the linear meters of logs in the stream within 5 m upstream and downstream of the transect were recorded in two size classes: those 5-20 cm in diameter and those greater than 20 cm in diameter. The amount of smaller material was given a subjective rating on a scale of 1 to 5, 1 being none or almost none and 5, huge accumulations, such as would be present in a debris dam.

Site variables recorded were stream gradient, stream width, elevation, and whether or not the area had been logged. Analysis of variance and regression statistics were used to estimate the effects of these parameters on substrate composition and amounts of organic debris.

DISCUSSION OF WATER QUALITY PARAMETERS

Turbidity - Turbidity is a measure of the degree to which light is scattered as it passes through water. It is generally caused by the presence of small suspended particles and colloidal material in the water. High turbidity can be harmful to trout and other aquatic life and also reduces the clarity of the water. It is also a rough indicator of suspended particulate mater, which is important as food for some aquatic insects (Hynes 1970).

Dissolved Oxygen - Dissolved oxygen was measured at the beginning of this study and found to be consistently at near saturated levels. Streams in the Smokies are so turbulent that gas exchange with the atmosphere is quite rapid, and oxygen does not become depleted.

Dissolved oxygen measurements were therefore discontinued and are not discussed further in this paper.

Discharge - Discharge is a measure of the volume of water flowing in a stream. Since this is clearly dependent on the size of the stream, a correction can be applied and the volume divided by the area of the watershed. Discharge is then reported in cubic feet per second per square mile (cfs/m^2) or liters per second per square km (ℓ/sec/km^2). Discharge measurements in this study were very rough and often could not be made because of excessive depth of the stream or ice cover. Discharge of streams in the Smoky Mountains has already been studied in detail by McMaster and Hubbard (1970), and discussion of discharge in this paper is based on that work.

Nitrate - Nitrogen is an essential nutrient to all plants, and nitrate is the form in which it is most abundant in streams. It can be a limiting nutrient to plant growth, but in streamwater it is generally more abundant than phosphorous.

Conductivity - Conductivity is a measure of the ability of water to conduct electricity. It is an indication of the total amount of dissolved ionic material in the water, although it cannot indicate what the ions are.

pH - pH is a measure of the acidity of the water. A pH of 7 is neutral and decreasing pH indicates increasing acidity. Low pH levels can eliminate many aquatic species as their tolerance for acid is limited. Acid inputs into streams can come from acidic minerals in rock, decaying vegetation, or acidic pollutants in the air, which are brought down in rain and snow.

Alkalinity - Alkalinity is a measure of how much acid must be added to the water to lower its pH to a given value. A pH of 4.7 was used as an end-point in this study and is one of the standard values used. High alkalinity indicates that the water is quite resistant to reduction in pH; low values mean very little acid must be added to lower the pH to 4.7. Alkalinity is usually the result of bicarbonate ion in the water. Bicarbonate is a product of the weathering of carbonate minerals and is also present to a limited extent as a result of dissolved carbon dioxide in the water.

Hardness - Hardness is the total amount of calcium and magnesium in the water. These elements are supplied mainly from the weathering of rocks, particularly limestone and dolomite. They are essential nutrients for all plants, but are generally abundant enough not to limit plant growth. Large quantities in water create the familiar problems associated with "hard water".

Specific elements - Ca, Mg, Na, K, and Si are five of the major elements found dissolved in streamwater. They were determined in a small number of samples in this study. For the most part, they are derived from rock weathering, although they are present to varying extents in organic material and rainwater.

Fecal coliform bacteria - These occur naturally in the intestines of all warmblooded animals. They are generally considered to be an indication of fecal contamination but are capable of maintaining populations in soil and stream sediments under warm conditions.

Fecal streptococcus bacteria - These are also present in the intestines of warm-blooded animals but are also abundant in soil, leaf litter, and cold-blooded animals, including insects.

Total coliform bacteria - These are the most abundant of the three types of bacteria considered in this study and the least strongly associated with fecal contamination. They occur in soil, decaying organic material, and stream sediments as well as the digestive systems of animals.

PHYSICAL STREAM CHANNEL CHARACTERISTICS

Results

Substrate Composition - Regressions of substrate composition against stream width, gradient, and elevation were run for each substrate size class. Gradient was the only parameter which showed a significant relationship. Larger substrate size classes were significantly more dominant on steeper streams; smaller sizes were more important when the gradient was less (Table 4). Exceptions to this were solid bedrock and the three smallest size classes, which showed no significant relationship to any of the site parameters. Small material appeared to be present in pools and backwaters and absent from areas of flowing water, no matter what the gradient. Bedrock tended either to completely dominate a section or to be absent. It is not included in Tables 4 and 5 because of this. Variation in bottom composition was extremely high (r^2 values quite low), even for the most significant relationship (Table 4).

An analysis of variance was used to compare substrate composition of logged and unlogged areas with similar gradients. No significant differences were observed (Table 5).

Organic Material - The only site variable which showed a significant ($p < .05$) relationship with the amount of organic debris in the stream was whether or not the watershed had been logged. This effect was strongest for the larger size class of woody debris. Approximately 3 times the

Table 4. Mean percent composition and correlation coefficients between substrate composition and gradient for each size class. (* Indicates $p < .05$. ** Indicates $p < .01$ $N = 85$)

Size Class	Mean Value	Correlation coefficient with gradient
Boulders > 3 m	5.0%	.63**
Boulders 1-3 m	24.0%	.49**
Rocks 30-100 cm	29.7%	-.37**
Rocks 10-30 cm	17.7%	-.42**
Rocks 3-10 cm	6.3%	-.28
Gravel	12.7%	-.31*
Sand	4.7%	-.24

Table 5. A comparison of bottom composition of logged and unlogged streams with gradient between 1 and 5%. No significant differences were observed (Analysis of variance $p > .05$)

Substrate		% in logged streams (N = 6)	% in unlogged streams (N = 42)
boulders	> 3 m	1.6	1.7
boulders	1-3 m	21.6	24.0
rocks	30 - 100 cm	34.0	33.9
rocks	10 - 30 cm	20.8	13.8
rocks	3 - 10 cm	6.3	6.4
gravel		11.6	17.9
sand		4.0	2.3

amount of large material was present in virgin streams as in those which had been logged. For the 5-20 cm size class, the difference was about twofold. No significant difference was observed between logged and virgin streams in the ratings for amount of smaller material, although the virgin areas had slightly higher ratings (Table 6).

Discussion

Although substrate composition is extremely important to nearly all forms of aquatic life (Hynes 1970), it is extremely difficult to analyze quantitatively. Techniques such as simply looking at the stream and estimating percentages of different size classes have problems in their lack of objectivity, particularly where more than one observer is involved. However, more objective methods, such as that used in this study, tend to be extremely time-consuming. Local variation is extremely high, so that large areas must be sampled in order to characterize a section of stream.

The composition of a streambed is determined largely by the capacity of the stream to move the rocks, which is in turn controlled by the velocity of the water. Water velocity is a function of stream volume and gradient, although other factors are also significant (Leopold et al. 1964). The greater the water velocity, the larger the particles which can be moved, and the larger the substrate left behind. Thus we expect increased gradient to increase the percentage of larger size classes in the streambed, as was observed in this study. Streams with greater average discharge should also have a somewhat greater percentage of larger size class material than smaller streams. Using stream width as an indicator

Table 6. Woody debris in channels of logged and unlogged streams. Figures represent the average number of meters of logs of each size class within 10-m sections of stream. * Indicates p < .01 (analysis of variance)

	Virgin streams (N = 16)	Logged streams (N = 74)
Logs > 20 cm *	7.06	2.24
Logs 5-20 cm *	8.06	3.97
Smaller material rating	1.69	1.59

of average discharge, we did not observe any differences in substrate composition. This is probably due to the extremely high variability due to local characteristics of the stream channel.

Differences in the amount of woody debris would be expected between logged and unlogged streams because an area which has been logged does not have the mature trees falling down which are present in the virgin areas. Most of the debris resulting from logging has rotted or washed down the stream. Since logging, input rates into the logged streams have probably been low, while those in the virgin area have continued to be relatively high. This difference is most pronounced in the larger size class, since few of the trees in the logged area have reached that size, while many are present in the smaller size. The amount of small material, mostly branchwood, contributed by virgin and formerly logged watersheds is almost the same because it is not as dependent on the age of the trees.

Some differences in the amount of wood might have been expected between large and small streams, since a larger area was included in the 10-m section of wider streams. Apparently, this was compensated for by the greater tendency of the larger streams to wash away the logs.

The significance of large organic debris in stream ecology has been pointed out in several studies (Swanson et al. 1976). Large logs can help to stabilize the substrate, filter out smaller debris to prevent it from being washed out of the stream, and provide a greater variety of habitat for stream-dwelling organisms. It is also a food source in itself for some organisms.

PHYSICAL AND CHEMICAL WATER QUALITY

Results

Elevation - Figures 2 to 5 show the relationships between water quality parameters and mean watershed elevation. For most parameters, only samples from watersheds underlain entirely by rocks of the Great Smoky group are included. For nitrate, turbidity and temperature data from all geological formations are shown since no significant variation with geology was observed for these parameters. Nitrate values for watersheds which were formerly at least 75% logged and those which were never more than 25% logged are shown separately. Summer and winter temperature values are also shown separately. Regression analysis revealed significant ($p < .05$) relationships with elevation for pH, alkalinity, nitrate, turbidity, summer temperature, Na, K, and Si. No significant relationships were found for conductivity, hardness, winter temperature, Ca, or Mg.

Geology - Since three of the major rock groups within the park are found only at the low elevations, one only at the high elevations, and one at all elevations (King et al. 1968), low elevation samples and high elevation samples were analyzed separately for geological influences. Streams draining different rock types at the low elevations (mean basin elevation below 900 m) are compared in Table 7. Hardness, conductivity, alkalinity, pH, nitrate, and turbidity values for the Great Smoky, Walden Creek, and Snowbird groups were analyzed using Duncan's multiple range test. The Great Smoky group streams were found to be significantly ($p < .05$) different from streams in both the Walden Creek and Snowbird groups for pH, conductivity, alkalinity, and hardness. The Walden Creek

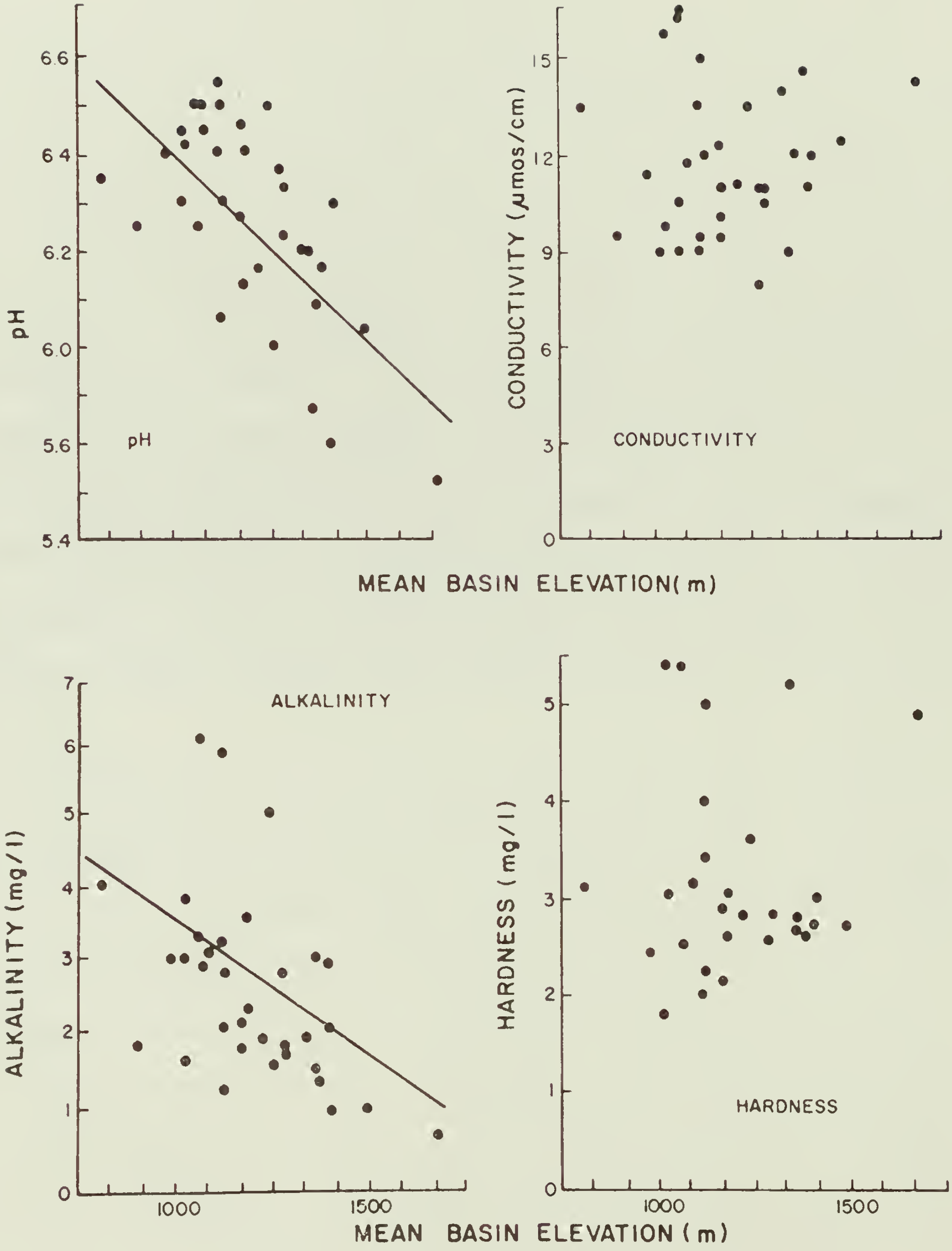

Figure 2. Variation in pH, conductivity, alkalinity, and hardness with elevation. Regression lines are shown where significant ($p < .05$).

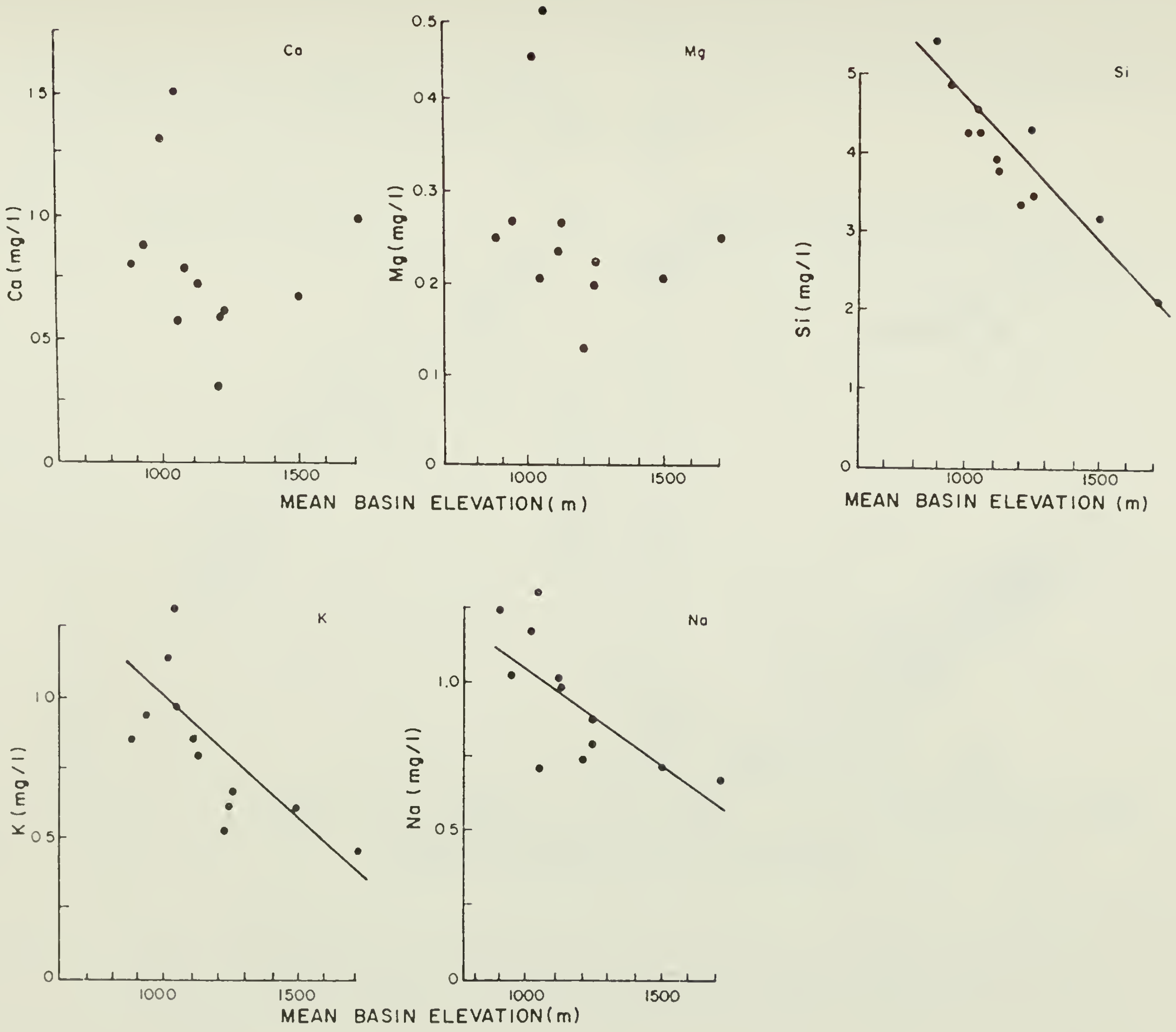

Figure 3. Variation in Ca, Mg, K, Na, and Si concentration with elevation. Regression lines are shown where significant ($p < .05$).

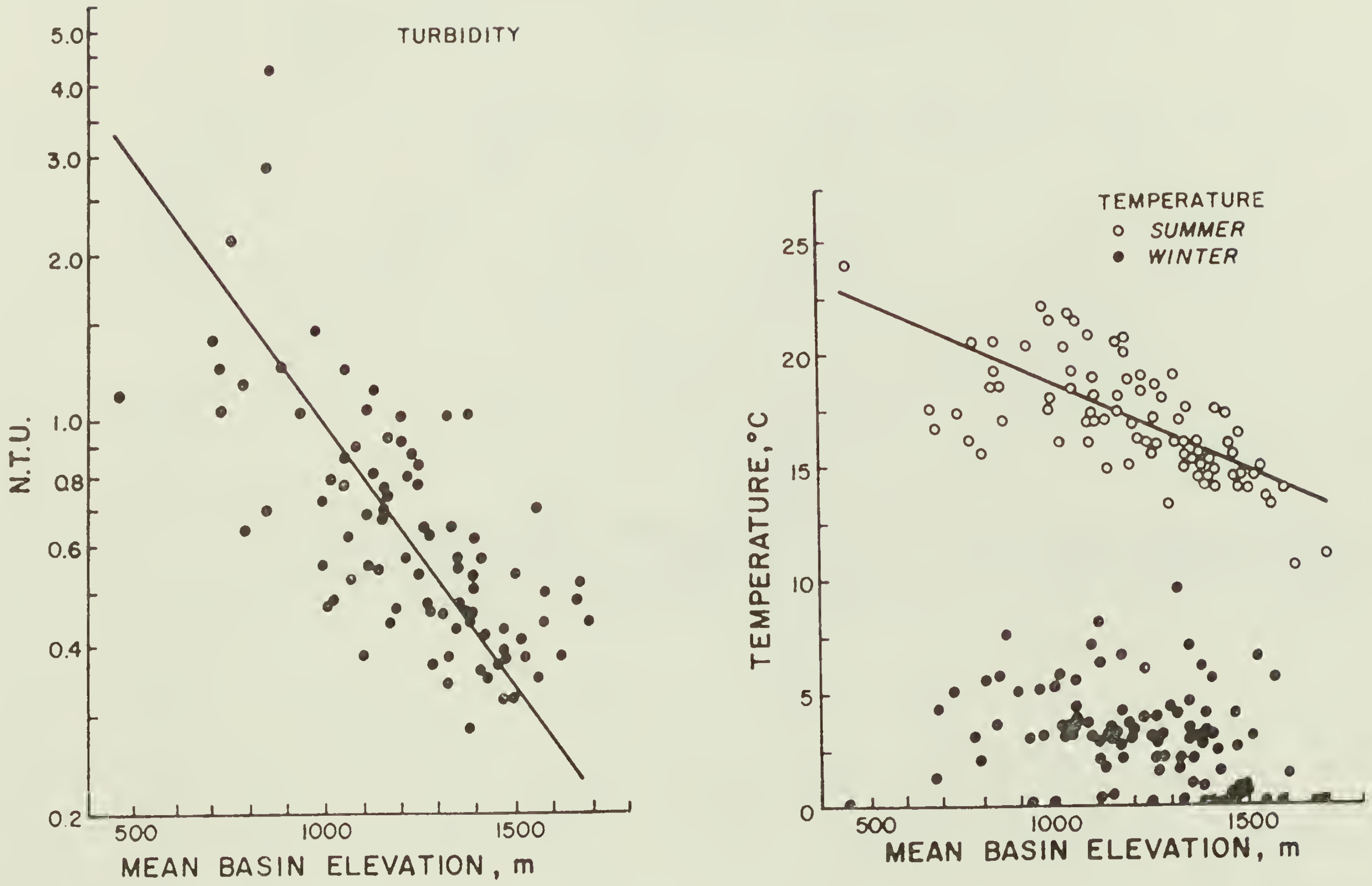

Figure 4. Variation in turbidity and temperature with elevation. Regression lines are significant ($p < .05$)

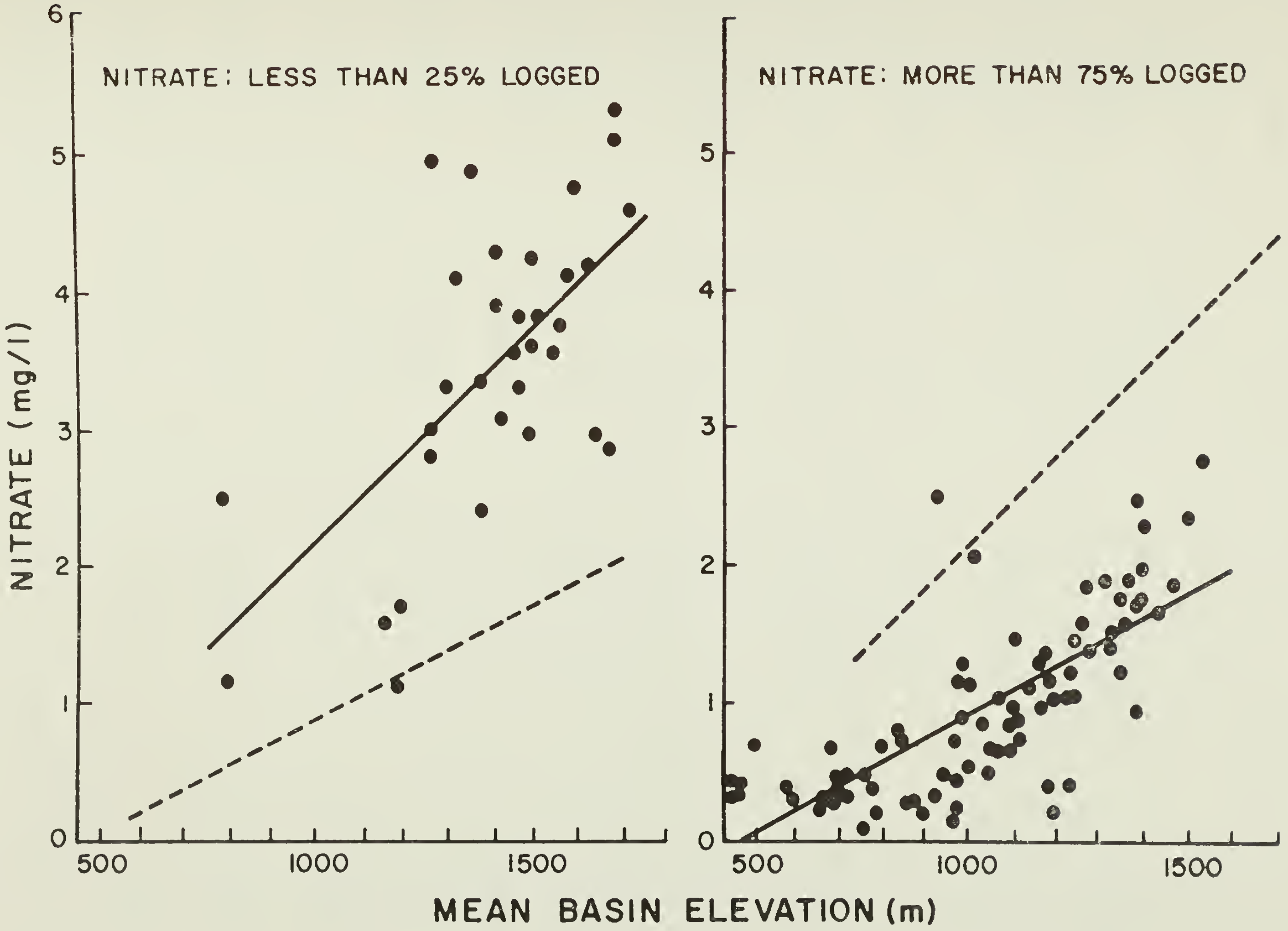

Figure 5. Variation in nitrate concentration with elevation. Logged (right) and unlogged (left) streams are shown separately. Regression lines for the two groups are significantly different (analysis of variance, $p < .01$)

Table 7. Water quality of streams in different geological groups. Only samples from streams with mean basin elevation below 900 meters are included (N in parentheses).

Parameter	At least 90% Great Smoky group	At least 70% Walden Creek group	At least 70% Snowbird group	1 station 25% Knox group
Hardness, mg/l as $CaCO_3$	3.35 (4)	8.90 (5)	6.30 (14)	44.8 (1)
Conductivity, µmhos/cm	13.5 (4)	25.5 (5)	20.4 (14)	92.4 (1)
Alkalinity mg/l as $CaCO_3$	2.85 (4)	7.30 (5)	6.1 (14)	40.1 (1)
Turbidity, N.T.U.'s	1.06 (4)	1.35 (4)	1.19 (13)	2.26 (1)
Nitrate mg/l as NO_3	0.95 (4)	0.43 (5)	0.53 (14)	1.63 (1)
pH	6.22 (4)	6.57 (5)	6.56 (14)	7.09 (1)
Calcium, mg/l	0.80 (1)	5.79 (1)	2.02 (3)	26.2 (1)
Magnesium, mg/l	0.28 (1)	1.78 (1)	0.60 (3)	3.46 (1)
Sodium, mg/l	1.24 (1)	2.18 (1)	1.85 (3)	1.36 (1)
Potassium, mg/l	0.82 (1)	1.37 (1)	0.86 (3)	0.82 (1)
Silicon, mg/l	5.08 (1)	6.29 (1)	6.12 (3)	4.13 (1)

and Snowbird groups were significantly different only in hardness. Specific element concentrations followed similar patterns, but there were not enough samples for statistical analysis.

High elevation (mean basin elevation above 1,350 m) streams underlain by Anakeesta formation are compared with those underlain by rocks of the Great Smoky group in Table 8. An analysis of variance was used to compare the two groups. Significant ($p < .05$) differences were seen for all variables except nitrate, Ca, and turbidity.

Effects of Pre-Park Logging - Streams which had a least 75% of their watersheds logged and those with no more than 25% of their watersheds logged are compared in Table 9. Only streams with mean watershed elevation between 1,200 m and 1,500 m are included because this offered the best balance of logged and unlogged watersheds within one geologic type (Great Smoky group) in a restricted elevation range. Although substantial differences between means were present for several parameters, only nitrate was significantly different (analysis of variance, $p < .05$).

Seasonal Variation - Monthly mean values of water quality parameters for Scratch Britches and LeConte Creeks, are shown in Figure 6. Scratch Britches Creek had much greater and more consistent seasonal changes, but significant differences were observed for both streams. The pattern for most parameters was for higher concentrations in the summer and lower in the winter. Discharge was highest in the winter and spring and lowest in the summer and fall. Nitrate concentrations were highest in the late winter and early spring and lowest in the fall.

Seasonal mean values of water quality parameters for the other streams, grouped into four elevation ranges, are shown in Figure 7. Samples from all geologic groups except the Knox group (limestone) were included in

Table 8. Water quality of streams in different geological groups. Only samples from streams with mean basin elevation above 1350 m are included (N in parentheses).

Parameter		At least 90% Great Smoky Group	At least 70% Anakeesta Formation
Hardness, mg/l as $CaCO_3$	*	4.55 (27)	6.70 (8)
Conductivity, µmhos/cm	*	18.4 (27)	24.7 (9)
Alkalinity, mg/l as $CaCO_3$		1.85 (27)	0.60 (9)
Turbidity, NTU's		.73 (27)	.36 (9)
Nitrate, mg/l as NO_3		2.98 (25)	3.79 (9)
pH	*	5.91 (27)	5.27 (9)
Calcium, mg/l		1.08 (9)	1.78 (4)
Magnesium, mg/l	*	0.32 (9)	0.75 (4)
Sodium, mg/l	*	0.74 (9)	0.48 (4)
Potassium, mg/l	*	0.66 (9)	0.47 (4)
Silicon, mg/l	*	3.17 (9)	2.44 (4)

*Significant at $p < .05$ (analysis of variance)

Table 9. Mean values of water quality parameters for logged and unlogged watersheds between 1200 and 1500 meters mean basin elevation (N in parentheses).

Parameter		At most, 25% of watershed logged		At least 75% of watershed logged	
Hardness, mg/l as $CaCO_3$		5.80	(14)	3.80	(24)
Conductivity, µmhos/cm		19.5	(14)	15.0	(25)
Alkalinity, mg/l as $CaCO_3$		1.60	(14)	2.35	(25)
Turbidity, NTU		.47	(14)	.58	(25)
Nitrate, mg/l as NO	*	3.66	(14)	1.61	(25)
pH		6.08	(14)	6.21	(25)
Calcium, mg/l		1.42	(7)	0.90	(11)
Magnesium, mg/l		0.52	(7)	0.30	(11)
Potassium, mg/l		0.63	(7)	0.74	(11)
Sodium, mg/l		0.71	(7)	0.83	(11)
Silicon, mg/l		3.20	(7)	3.71	(11)

* $p < .05$

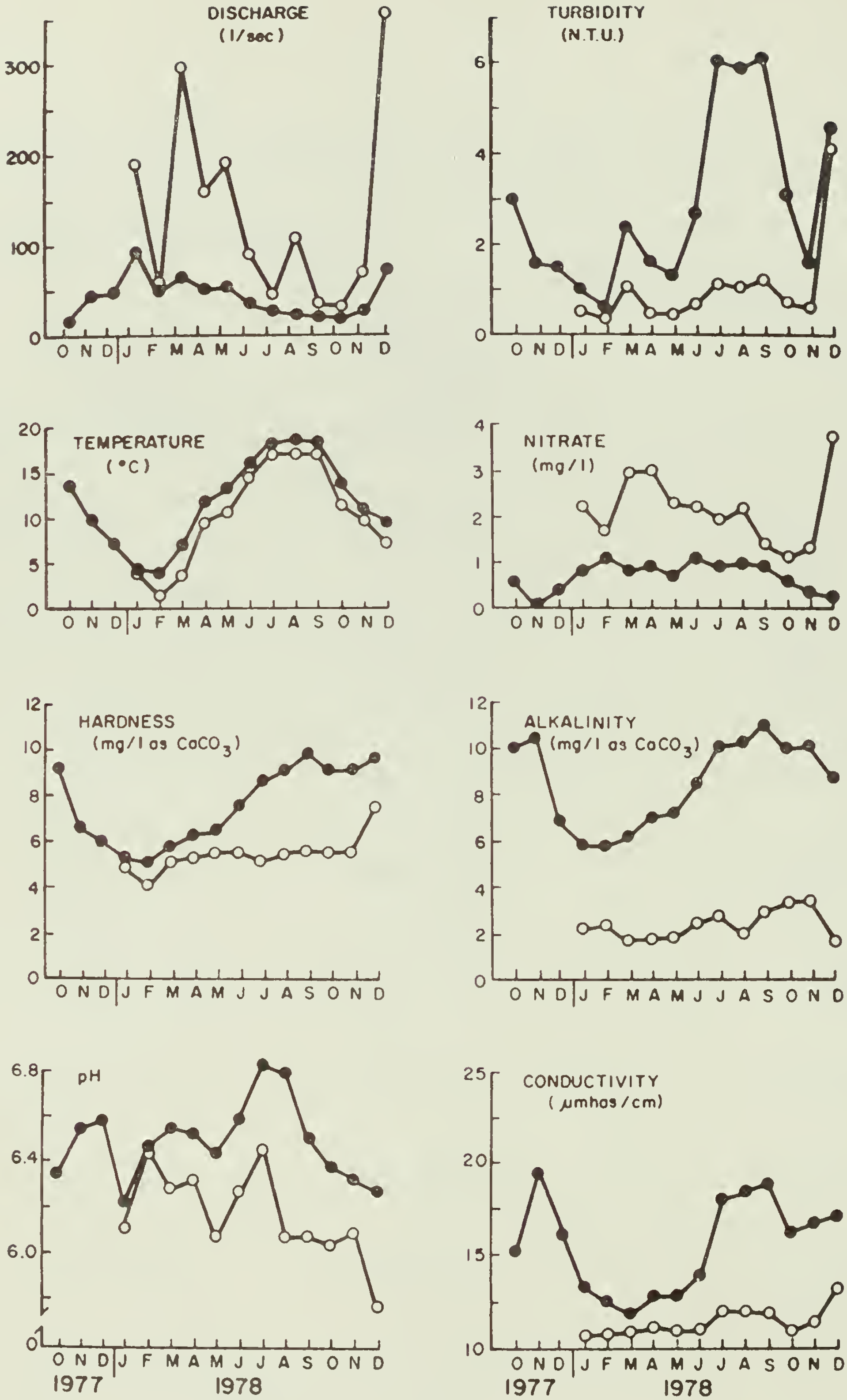

Figure 6. Monthly mean values of water quality parameters in Scratch Britches Creek (solid circles) and Leconte Creek (open circles).

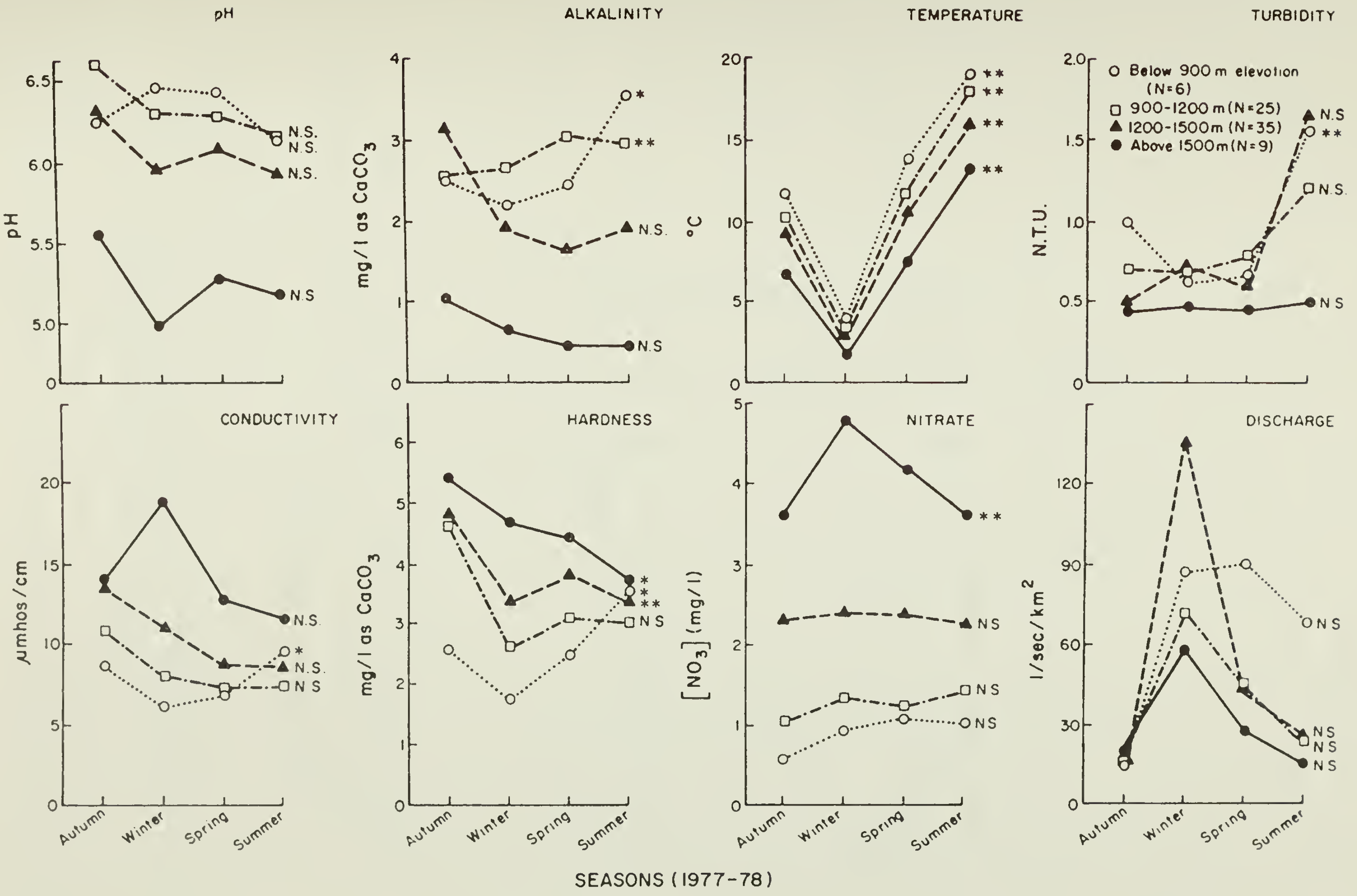

Figure 7. Seasonal mean values of water quality parameters for all stations sampled, grouped in 4 elevation ranges.

* Indicates summer value is significantly different from winter (paired t-test, $p < .05$). ** Indicates $p < .01$.

this analysis. A paired t-test was used to compare summer and winter values for significant differences. In general, patterns in the low elevations were similar to those observed on Scratch Britches and LeConte Creeks. Summer values of alkalinity, conductivity, and turbidity were significantly ($p < .05$) higher than winter values at the low elevations but not at the high. For pH, no significant difference was seen at any elevation. Winter nitrate concentrations were significantly higher than summer at the high elevations but not significantly different at the low elevations. Temperature and hardness were the only parameters to show significant differences between winter and summer values at both high and low elevations. Seasonal patterns in nitrate concentrations in logged and unlogged watersheds are compared in Figure 8. No significant differences between seasons were observed for either logged or unlogged streams (Duncan's multiple range test, $p > .05$).

Data from a U.S. Geological Survey gauging station on the Little River (Anon. 1963-78) were used to compare discharge and temperature for the year of this study with data from other years (Fig. 9). Values for 1977-78 were well within the range seen in other years, but there were differences from the average for the period of the USGS records. Temperatures for the period of this study were lower in the winter and higher in the summer than average. Discharge was lower than average in the summer and extremely low in the month of February. While it is clear that no year exactly matches the average, some consideration should be given to what effect these differences will have on the water quality data collected in this study. The greater than average extremes in temperature and dryer-than-average summer would probably emphasize the seasonal differences in water quality. The extremely low discharge in February would tend to suppress these

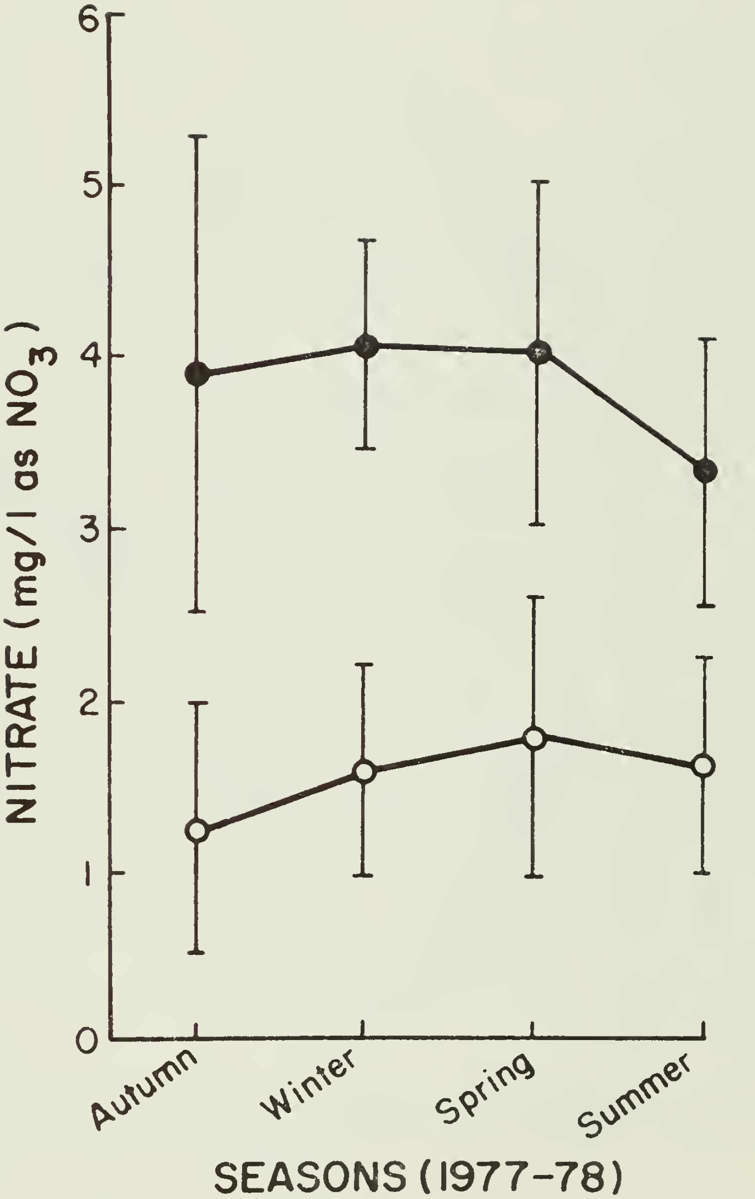

Figure 8. Seasonal patterns in nitrate concentrations in logged (open circles) and unlogged (solid circles) streams. Mean values ± standard deviation are shown for samples between 1200 and 1500 meters mean basin elevation.

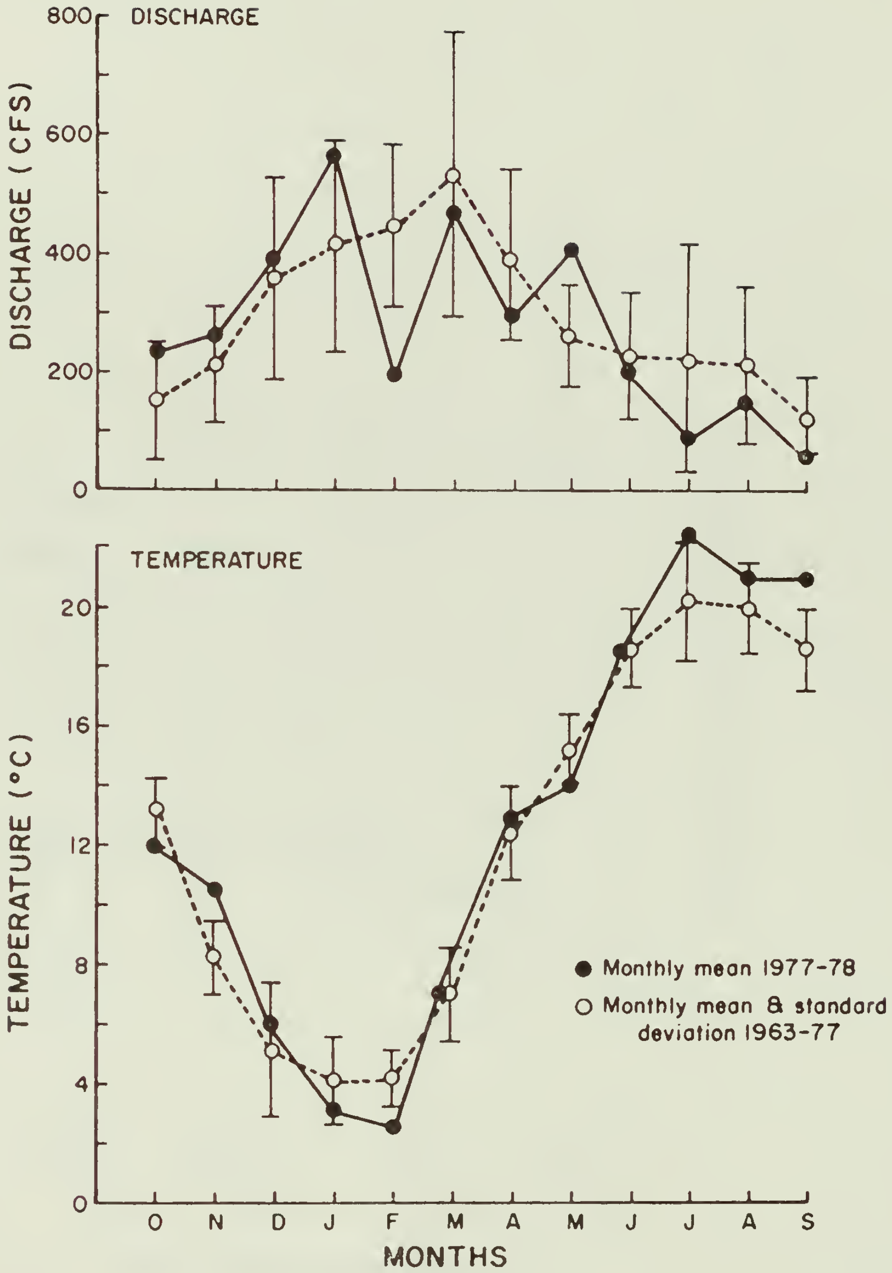

Figure 9. A comparison of monthly mean temperature and discharge of the Little River near the park boundary from October 1977 to September 1978 with mean and standard deviation of monthly means from 1963-1977. From U.S.G.S. data (Anon., 1963-78).

seasonal differences, although not dramatically, since other winter months were near or above normal. Thus, seasonal water quality variation observed in this study might be somewhat more pronounced than it would have been in an "average" year.

Fluctuations in water quality - Changes in streamwater quality were observed on time scales ranging from a few hours to several months. A nested analysis of variance was performed on daily water quality samples from Scratch Britches and LeConte Creeks to determine how much variation was associated with different time periods (Table 10). For some parameters, such as pH, most of the variation was accounted for by day to week fluctuations. For others, such as temperature, most of the variation was on a seasonal basis. This type of analysis was impossible with data from other streams because of the high variability between streams and the small number of samples from any one stream. Correlation coefficients were determined, however, between data from Scratch Britches and LeConte Creeks and data from four other streams taken at the same times (Table 11). These, together with the great differences between results from Scratch Britches and LeConte Creeks (Table 10) showed that considerable variety exists between the behavior of different streams. Except for temperature, fluctuations in water quality of one stream were not predictable from those in another stream.

Short Term Variations - Twenty-four hour diel studies on several streams under conditions of stable flow showed no significant changes in any parameters other than temperature. Daily fluctuations in water temperature were closely related to changes in air temperature. Changes in water temperature over 24-hour periods ranged from less than 1°C when air temperature was fairly stable to a drop of 6.5°C immediately following passage of a cold front. Maximum-minimum temperatures of

Table 10. Percent of the variance in water quality parameters on Scratch Britches Creek (S.B.) and LeConte Creek (L.C.) associated with different time scales (nested analysis of variance).

Parameter	Season	Month	Week	Day
S. B. Temperature	84.4	9	3.9	2.7
L. C. Temperature	85.8	7.8	4.1	2.3
S. B. pH	13.7	16.1	14.8	55.4
L. C. pH	0.0	25.1	33.9	41.0
S. B. Conductivity	56.4	2.6	4.9	36.1
L. C. Conductivity	12.7	0.0	9.7	77.6
S. B. Alkalinity	64.0	21.1	5.1	9.8
L. C. Alkalinity	13.1	18.3	49.5	19.1
S. B. Hardness	62.3	16.7	5.8	15.2
L. C. Hardness	13.3	9.2	42.3	35.2
S. B. Nitrate	22.8	28.5	0.3	48.4
L. C. Nitrate	9.7	16.2	26.1	48.0
S. B. Turbidity	39.2	1.7	9.9	49.2
L. C. Turbidity	1.8	0.0	0.0	98.2
S. B. Discharge	32.4	12.2	27.1	28.3
L. C. Discharge	4.8	1.6	16.5	77.1

Table 11. Correlation coefficients between water quality parameters of LeConte Creek and Scratch Britches and those of other streams. Only correlation coefficients greater than .60 are significant at $p < .05$ (N in parentheses).

Location	pH	Cond.	Alk.	Hard.	Turb.	Nit.	Temp.
West Prong, Little Pigeon River at park boundary							
To Scratch Britches	.61 (12)	.68 (12)	.65 (12)	.70 (12)	.62 (12)	-.19 (12)	.97 (7)
To LeConte Creek	.80 (11)	.60 (11)	.96 (11)	.39 (11)	.56 (11)	.50 (11)	.95 (6)
Middle Prong, Little Pigeon River at park boundary							
To Scratch Britches	.81 (10)	.39 (10)	.47 (10)	.52 (10)	-.09 (10)	--	--
To LeConte Creek	.31 (7)	-.28 (7)	.62 (7)	.31 (7)	.26 (7)	--	--
Little River at park boundary							
To Scratch Britches	.13 (12)	.63 (12)	.36 (12)	.94 (12)	.97 (12)	.02 (12)	.99 (8)
To LeConte Creek	.78 (11)	.38 (11)	.71 (11)	.54 (11)	.99 (11)	.83 (11)	.99 (8)
Walker Prong above U.S. 441							
To Scratch Britches	-.13 (11)	.56 (11)	.00 (11)	-.07 (11)	-.04 (11)	-.24 (11)	.95 (9)
To LeConte Creek	.04 (7)	.62 (7)	.00 (7)	-.19 (7)	.56 (7)	.58 (7)	.97 (5)

Scratch Britches and LeConte Creeks showed daily changes ranging from 0°C to 11°C, with daily variations generally being higher in winter than summer (Fig. 10).

Twenty-four hour diel studies during periods of heavy rain, on the other hand, showed dramatic changes in water quality. Results were highly varied, however, as to exactly what types of changes occurred. One example is shown in Figure 11.

Comparison of samples taken from Scratch Britches and LeConte Creeks before storms with those taken the day after the storms shows the general trend of these changes. A paired t-test was used to analyze the results for statistical significance (Table 12). It should be remembered that these samples were taken every morning, regardless of weather conditions, and that, consequently, there is no consistency as to how long before or after the peak flow the samples were taken. The only requirement for inclusion in the analysis was that discharge on the second day be at least 25% greater than the day before. For most parameters, storms either produced similar effects at all times of the year or effects so variable that no general trends were apparent. One exception to this was nitrate concentrations in LeConte Creek. While no significant effect was seen over the entire year, a dramatic increase in nitrate levels following storms was observed in the spring.

Discussion

Seasonal variation - Seasonal changes in water temperature closely follow changes in air temperature, with rapid change in April and October and little change through summer and midwinter (Shanks 1954). Changes of

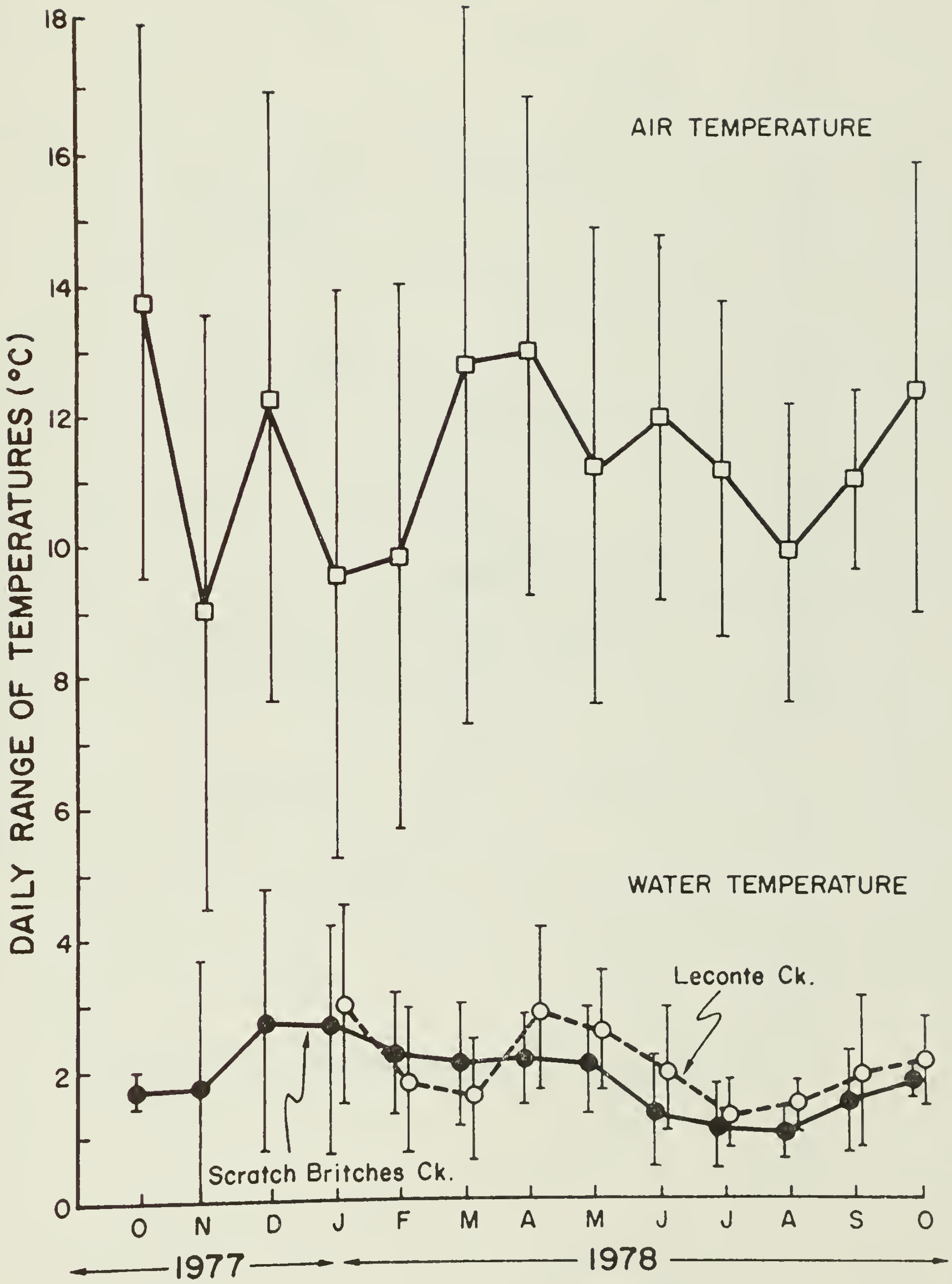

Figure 10. Monthly mean and standard deviation of daily fluctuation in Scratch Britches Creek water temperature (solid circles), LeConte Creek water temperature (open circles), and air temperature (squares).

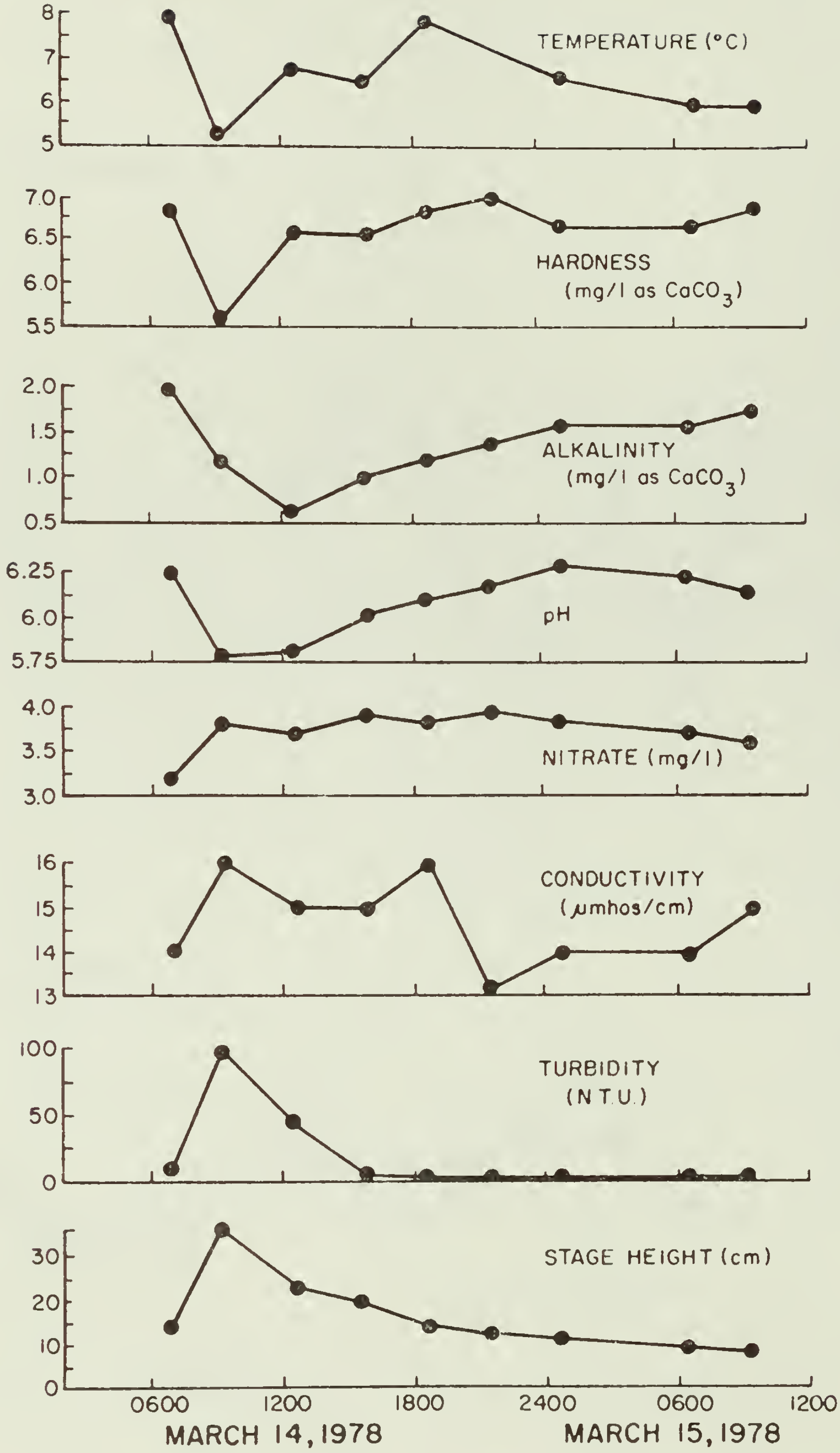

Figure 11. Water quality of the West Prong of the Little Pigeon River following a storm, March 14-15, 1978. 0.82 Inches of rain fell between midnight and 7:00 a.m., March 14.

Table 12. Changes in water quality due to storms on Scratch Britches and LeConte Creeks. Values represented mean change for all days when discharge increased by at least 25%. * Indicates $p < .05$ (paired t-test). ** Indicates $p < .01$.

Parameter	Scratch Britches Creek	LeConte Creek
pH	-.03 (N=21)	-.19** (N=22)
Conductivity	+2.05* (N=21)	+1.14** (N=22)
Temperature	+ .27 (N=21)	+.03 (N=20)
Alkalinity	+ .66 (N=21)	-.46** (N=22)
Hardness	+1.37**(N=21)	+.40** (N=23)
Nitrate	+.21 (N=20)	+.47 (N=23) In spring +.83* (N=10)
Turbidity	+4.13* (N=19)	+1.10 (N=23)

water temperature are greater in the low elevations than high, as freezing of high elevation streams prevents them from cooling below 0°C.

Discharge measurements in this study were too sporadic and inaccurate to draw any statistical conclusions except from Scratch Britches and LeConte Creeks. While patterns of rainfall are fairly constant throughout the year, with minor minimums in spring and fall (unpublished data), discharge from the two streams at low elevation was much lower in summer and fall. The same pattern is seen in the USGS records from the Little River (Fig. 9). This is due to increased evapotranspiration during the growing season. McMaster and Hubbard (1970) showed that reduction in flow during low flow periods is much greater in the low elevations than the high. This is presumably due to the warmer, dryer climate of the lower elevations, which results in a greater loss through evapotranspiration.

Seasonal patterns of water quality are probably related to these changes in temperature and discharge. Greater evapotranspiration during the growing season lowers the water table, resulting in longer retention time of water in the soil. This gives water a greater time to dissolve minerals from the soil; consequently, geologically derived minerals such as Ca, Mg, Na, K, and Si (reflected in this study in conductivity, hardness, and alkalinity) are likely to be more concentrated during the summer months. This difference is only significant in the low elevations, where differences between winter and summer in temperature and discharge are the greatest (McMaster and Hubbard 1970).

Turbidity is also higher during the summer, although the reason for this is unclear. Increased discharge would dilute the turbidity unless balanced by increased inputs of particles. The presence of a seasonal difference in the low elevations but not the high suggests that it is either streamflow or temperature which is the main influence, but some knowledge of the composition of the particles involved would be necessary to draw any concrete conclusions about the changes in turbidity.

Nitrate concentrations were lowest in the autumn, decreasing gradually from late winter through midsummer, then rapidly through late summer and autumn. This is probably related to patterns of leaf decomposition and nutrient uptake processes. Nutrient uptake is greatest during the growing season, resulting in a gradual depletion through the course of the summer. Leaf fall in the autumn provides a sudden pulse of organic material. Initially, nitrogen is taken up by micro-organisms in the first stages of litter breakdown (Triska et al. 1975), reducing nitrate concentrations in the autumn. As litter decomposition progresses, the nitrogen present in the leaf litter begins to be released. This, together with the reduction in uptake by the trees, is probably responsible for the buildup of nitrate through the winter.

Although this pattern for nitrate is fairly clear in Scratch Britches and LeConte Creeks, a significant seasonality was not observed for the overall data except in the high elevations. Vitousek and Reiners (1975) found distinct seasonal patterns in nitrate concentrations in logged areas but not in virgin areas. This distinction was not observed in this study. That levels of nitrate are different between logged and unlogged watersheds is not, in itself, a reason to expect seasonal patterns to be different. Both logged and unlogged forests should have similar seasonal patterns in nutrient uptake and release, even though the balance between uptake and release is different. The difference in results between Vitousek and Reiner's study in New Hampshire and this study can probably be explained best by differences in climate. The much longer and more severe winters in New Hampshire and in the high elevations of GRSM result in a longer and more complete cessation in nutrient uptake by the forest. The short mild winters of the low elevations in GRSM are probably not enough to have a significant impact on nitrogen balance in the forest floor.

Elevational gradients - Air temperatures in the Great Smoky Mountains decrease approximately 4.1°C for every 1,000 m increase in elevation at all times of the year (Shanks 1954). Streamwater temperatures decrease by more than this (7.0°C/1,000 m) in the summer but follow no definite pattern in the winter. The extremely high temperature gradient in the summer may be due to use in this study of mean basin elevation rather than the elevation where the sample was taken. This requires the assumption that the water quality observed at the sampling site represents an average of water from all parts of the drainage basin. While this is reasonable for most parameters, water temperature might reflect not only the temperature of the air at the source of the water but also at the point where the sample was taken. If this were the case, use of mean basin elevation would cause an overestimate of the temperature gradient. Another reason might be warming of the stream channel by solar radiation. Since cloud cover and shading by vegetation are both generally greater in the high elevations, radiative warming would be more significant in the low elevations.

The lack of a distinct temperature gradient in the winter is presumably due to the inability of liquid water to cool below 0°C under normal conditions. The difference in air temperature is reflected in increased freezing of high elevation streams rather than in low water temperatures.

Average stream discharge per km^2 has been shown to be approximately two times as great at high elevations as at low elevations, with an even greater difference during low flow periods of summer and autumn (McMaster and Hubbard 1970). This is due both to greater rainfall and lower potential for evapotransporation in the high elevations than the low.

Elevational gradients in other water quality parameters are probably related to these gradients in temperature and streamflow. The degree to which minerals are leached from the soil and bedrock is determined to a large degree by the retention time of water in the ground. Alkalinity and pH also are partially determined by the degree of buffering of acidic rainwater by contact with soil and bedrock (Johnson et al. 1972). The more time groundwater spends in contact with soil and bedrock, the more time there is for chemical reactions to occur. In the high rainfall, high discharge situation found in high elevation watersheds, water flushes through the ground relatively quickly and there is less time for chemical reactions to occur. In the low elevations, where groundwater retention times are longer because of the dryer conditions, streamwater has higher concentrations of geologically derived elements and higher pH and alkalinity. The low temperatures of the high elevations may also slow chemical weathering rates (Gorham et al. 1980). Furthermore, inputs of acid from acidic soils of the high elevation spruce-fir and heath communities may influence elevational gradients, particularly of pH and alkalinity. It is also possible that differences in soil depth between high and low elevations might influence retention time of groundwater, and thus water quality. It is not clear why Ca, Mg, hardness, and conductivity did not follow elevational gradients, while other geologically influenced parameters did, since they should be controlled by similar processes and were found to have similar gradients in the White Mountains of New Hampshire (Vitousek 1977). Perhaps variations in rock composition within the Great Smoky group or differences in uptake between logged and unlogged forests obscure any elevational trends for these parameters.

The elevational gradient in turbidity is probably also related to gradients of flow and temperature. The pattern of decreasing turbidity with increasing elevation, summer increases in turbidity, and greater seasonal fluctuation in the low elevations than high closely parallels that of discharge and temperature. Greater stream discharge would decrease the concentration of turbidity-causing particles unless balanced by greater inputs of particles. Temperature should increase some kinds of biological activity which might cause increased turbidity. Too little is known about the sources and composition of the turbidity to do more than speculate on possible reasons for the distinct elevational gradient.

Nitrate concentrations in streamwater are mediated primarily by biological factors in the soil and plant community (Vitousek 1977, Feth 1966). Nitrogen cycling within the forest system is quite large relative to outputs in streamwater (Bormann et al. 1977). Because of this it is difficult to interpret streamwater nitrate concentrations without detailed study of nitrogen movements and transformations within the forest system. Nitrate concentrations in streamwater from other forested watersheds in western North Carolina and eastern Tennessee, some with elevations and forest types similar to those in this study, have been found to be less than 0.1 mg/ℓ (Swank and Douglas 1977, J. Elwood, personal communication). Because of this, it seems likely that the relatively high nitrate levels and distinct elevational gradients in nitrate concentration observed in this study are related to forest floor and soil characteristics rather than forest composition.

Bedrock type - The supply of elements from the weathering of rocks depends both on the original rock composition and on the rate of weathering. In general, plutonic rocks weather much more slowly than those of sedimentary origin, resulting in streams with low concentrations of dissolved solids (Johnson and Reynolds 1977, Miller 1961). This is due both to the absence of more soluable minerals such as carbonates and to the massive structure and low porosity which limit penetration of the rock by water. Sedimentary rocks, being highly variable in both structure and mineral composition, produce great variability in stream chemistry (Ponce et al. 1978). That the geological formations of the GRSM vary in structure and composition (Table 2) is directly reflected in the chemical composition of streams.

Since the Great Smoky group is the predominant rock group in the park and occurs at all elevations, it is used as a baseline with which to compare other rock groups. It consists of thick-bedded sandstones composed principally of quartz and potassic feldspar (King et al. 1968). This massive structure and lack of easily weathered minerals results in streams with extremely low concentrations of dissolved minerals similar to those described for plutonic rocks in other areas (Johnson and Reynolds 1977, Miller 1961).

The Anakeesta formation consists mainly of silty and clayey rocks metamorphosed to slate, phyllite, or schist. The main factor which distinguishes it chemically from other rocks of the group is the presence of significant quantities of pyrite and other sulfides which dissolve to form sulfuric acid (King et al. 1968; Herrmann et al. 1976). This results in lowered pH and alkalinity and increased hardness, conductivity, and magnesium concentrations. This is similar to the effect described for pyritic rock in West Virginia (Ponce et al. 1978). The low concentrations of Na, K, and Si suggest a smaller concentration from feldspar minerals, probably reflecting the dominance of clay minerals over feldspars in the present rock.

Although the Walden Creek group is composed primarily of shales and siltstones, the dominant influence on streamwater chemistry comes from minor layers of limestone and dolomite as well as limestone pebbles in some of the conglomerates (King et al. 1968). This results in elevated hardness, alkalinity, pH, and Ca and Mg concentrations. The increases in Na, K, and Si may be due to the finer texture and weaker structure of the rocks or to smaller amounts of quartz relative to more easily weathered minerals such as feldspars.

The Snowbird group is similar to the Walden Creek group in that it is highly varied but composed mainly of shales and siltstones (King et al. 1978). This results in the generally higher concentrations of most minerals in the streamwater as compared to the Great Smoky group. Although occasional layers of carbonate-rich siltstone are present, the limestone and dolomite of the Walden Creek group are absent. Consequently, the increases in Ca, Mg, hardness, and conductivity are not as great.

The Knox group, as present in the park, consists entirely of limestone (King et al. 1968). The high porosity and solubility of the limestone causes a dramatic rise in hardness, conductivity, alkalinity, pH and Ca and Mg concentrations.

Forest Succession - Second growth forests, which are accumulating biomass at a substantial rate, have been shown to lose significantly less nutrients in stream water than old growth forests which are no longer increasing in biomass (Martin 1979, Vitousek 1977, Vitousek and Reiners 1975). This has been attributed to the accumulation of nutrients in the increasing biomass of the second growth forest. A mature forest, on the other hand, would be in a steady state with regard to nutrient inputs and outputs (Vitousek and Reiners 1975). In this study, only nitrate showed significantly lower concentrations in streams draining logged watersheds than those in unlogged areas. This effect was quite pronounced, unlogged watersheds showing more than twice the nitrate levels of those which had been logged prior to the establishment of the park.

A comparison of the ratio of stream water nutrient concentrations in virgin and unlogged watersheds observed in this study with ratios observed by Vitousek and Reiners (1975) and Martin (1979) shows substantial differences between the three studies (Table 13). Vitousek and Reiners (1975) found a much greater difference in nitrate levels than either Martin (1979) or this study. This could be due to the relative age of the successional stands used in the three studies, or to different forest composition. Vitousek and Reiners used much younger forests (27-29 years) than either Martin (55 years) or this study (40-80 years). In addition, stands studied by Vitousek and Reiners were higher in elevation than those studied by Martin and farther north than those of the present study. The more severe climate may result in slower succession for the forests of Vitousek and Reiners. The older forests have had more time to approach an equilibrium state and are likely to be more similar to old-growth forests than are the younger stands of Vitousek and Reiners.

Table 13. Ratios of streamwater nutrient concentrations in virgin watersheds to logged watersheds. A comparison of data from 3 studies.

Nutrient	Vitousek & Reiners (1975)	Martin (1979)	Present study
NO_3	6.62	1.41	2.27
K	1.81	3.00	0.84
MG	1.66	1.16	1.72
Ca	1.56	1.69	1.58
Na	1.03	1.44	0.86

The forests studied by Vitousek and Reiners were spruce-fir, those studied by Martin were hardwood, and those in this study were mixed and highly variable in composition. While it is not clear what the effect of these differences would be, we would expect to see some differences between different forest types. Differences between the three studies in ratios for nutrients other than nitrate are probably not related to forest succession, as differences observed in this study were not statistically significant and those observed by Martin (1979) were attributed to differences in soil between his watersheds rather than to differences in the forests.

Short term variation - Although some observers (McSwain and Swank 1977, Minckley 1963) have reported consistent diel changes in pH, alkalinity, and dissolved oxygen of stream water associated with photosynthetic activity in the streams, this was not observed in this study.[1/] Daily changes in water temperature, however, did occur. Two main factors probably combine to increase water temperatures during the day and decrease them at night. The first is the temperature of the air, which is warmer during the day. Contact between water and air is high due to the turbulence of the streams, so heat is transferred from air to water during the day when the air is warmer than the water and transferred from water back to air when the air is cooler, during the night. The second factor is direct radiation of heat to and from the streambed. During the day, sunlight is absorbed by the rocks of the streambed, warming them and thus the water.

[1/] Since the completion of the project, new studies using continuous recording pH meters have detected diurnal patterns for pH during summer.

During the night the rocks radiate back to the atmosphere, thus cooling the water. The greater temperature fluctuation in winter than summer is probably due to the open canopy during the winter. Without leaves shading the streams, they receive much more sunlight during the day and radiate more to the sky during the night. Air temperature fluctuations were not significantly different in winter than in summer.

Under normal conditions, water flowing in the streams of the Smokies comes from deep groundwater and has spent a considerable period of time there before seeping to the surface and entering the stream. It is thus fairly constant in character, having been buffered by long contact with the soil and bedrock. During and immediately after heavy rain the ground becomes saturated with water and much of it moves rapidly through the upper layers of the forest floor, or even on the surface. At first approximation, therefore, water quality of streams swollen with rain could be expected to be more similar to rainwater than normal: lower in pH, dissolved minerals and bacteria, and either lower or higher in nitrate, depending on the chemical composition of the rain. This is complicated, however, by the characteristics of the upper layers of the forest floor, which are very different from the subsoil and bedrock from which the ground water normally comes. Decaying leaf litter and wood are a source of many nutrients and tend to be acidic. Bacteria also flourish in the decaying organic material. The topmost, organically enriched horizons are therefore much higher in easily removed nutrients, acids, and bacteria than are lower soil horizons. Water reaching the streams directly through these upper layers ("quick return ground water") is likely to be enriched in organic material, bacteria, and nutrients such as nitrate, which are easily removed (Bradford and Iwatsubo 1978). It may, in addition, be lower in pH than ground water from lower in the soil. One further factor influencing water quality after storms is the increased volume of flow, which greatly increases the ability of the stream to carry suspended sediments. Thus turbidity and suspended material are generally higher in concentration after a storm, as would be expected.

The reaction of a stream to a given rainstorm, therefore, depends on many factors. The degree to which the soil is already saturated has a great influence on how much increased runoff will occur and to what extent it will be from the uppermost soil horizons. The time of year will affect the state of decomposition of the previous fall's leaf litter and thus the extent to which it affects the water chemistry. The bedrock composition will affect the soil chemistry and thus its effect on ground water. The duration and intensity of rain and its original chemical composition will also be important. Thus it is not particularly surprising that patterns of water quality change following storms are extremely variable. In general, the following trends were observed:

(1) In LeConte Creek, pH generally decreased following a storm, sometimes as much as a full unit. Scratch Britches Creek also decreased by as much as a full pH unit at times but also increased in pH at times, so showed no statistically significant difference. This is probably due to the greater alkalinity of Scratch Britches Creek than LeConte Creek, and therefore greater resistance to change in pH. The depression of pH is probably due to already acidic rain receiving less contact with the bedrock and therefore less buffering. There may also be some contribution of acids from decaying organic material. The degree to which the increasing acidity of precipitation in the area

affects this change is not certain (see acid rain section, page 65).

(2) Conductivity generally increased following storms. Since rain generally has a lower conductivity than stream water, this probably reflects substances picked up from contact with the upper layers of the forest floor. This pattern is reversed on Abrams Creek, where ground water flowing through limestone is normally quite high in conductivity but is diluted during high flow by water which does not reach the depth of the limestone layer (Raymond C. Mathews, Jr., unpublished data).

(3) Hardness generally increased, probably controlled by the same factors as conductivity.

(4) Temperature showed no consistent pattern.

(5) In LeConte Creek, alkalinity generally decreased, probably due to the lowered pH and low buffering capacity of the water. Alkalinity of Scratch Britches Creek showed no consistent pattern, sometimes increasing, sometimes decreasing, as did its pH.

(6) Nitrate, although it did not show any consistent pattern over the entire year, did increase dramatically after storms for a period in the spring. Presumably, this was a time when the previous autumn's litter fall was decaying rapidly and much nitrogen was being released at the soil surface. Nitrate levels remained high for a considerable period after the storm because nitrate was flushed from the upper levels of the forest floor not only into the stream but also into the deeper ground water which entered the streams over an extended period after the storm.

(7) Turbidity generally increased, probably due to the greater ability of the stream to carry sediment and to the washing in of material from stream banks.

(8) Storms observed over 24-hour periods generally showed dramatically increased levels of bacteria (see bacteriological section, page 60), presumably due to material washed in from forest floor and streambank.

Again, it should be emphasized that this is only what occurred on the average. All parameters were extremely variable in their response to storms.

GROUPING OF STREAMS

Results

A cluster analysis (SAS PROC CLUSTER, Barr et al. 1976) was used to objectively group streams on the basis of similarity in water quality. The parameters pH, alkalinity, conductivity, hardness, turbidity, and nitrate were weighted equally, and stations which were most similar in these parameters were grouped together. Only stations with samples during all four seasons were included. These were combined into 12 main groups. Table 14 lists the sample stations present in each of the 12 groups. Table 15 shows mean water quality values for each group. Figure 12 shows the cluster map, which indicates which of the 12 main groups are most similar and which most different.

Group 1, the largest group of streams, contained those with all water quality parameters at near average values. This included many low to medium elevation stations on main streams. These generally had large watersheds and drained a variety of elevations, geologic types, and forest types. Because of the variety of terrain covered by each watershed, values of water quality parameters represented an average of different extremes. Some smaller streams were also included. These were generally at intermediate elevations, with at least some of the

Table 14. Sample areas included in each cluster group.

Group	Location
Group 1.	Cosby Creek at park boundary
	Middle Prong, Little Pigeon at park boundary
	Little River from park boundary to junction with Fish Camp Prong
	Middle Prong, Little River
	Anthony Creek above Cades Cove
	Oconaluftee River from park boundary to 990 m
	Raven Fork and Bradley Fork at confluence with Oconaluftee River
	Big Creek from 750 m to 1100 m
Group 2.	Mill Creek at confluence with Abrams Creek
Group 3.	Panther Creek at Parsons Branch Road
	Twenty-mile Creek at park boundary
	Noland Creek and tributaries below 1100 m
	Kephart Prong at its base
	Leatherwood Branch (tributary to Big Creek near park boundary
Group 4.	Middle Prong, Little Pigeon River at Ranger Station
	Porters Creek at its base
	W. Prong, Little Pigeon River from Sugarlands to park boundary
	Gunter Fork at its base
	Beech Flats Creek above U.S. 441
Group 5.	W. Prong, Little Pigeon from 510 m to 1275 m

Table 14. Continued

Group	Location
Group 6.	Middle Prong, Little Pigeon and Ramsay Prong from Porters Creek to 900 m Alum Cave Creek Bearpen Hollow (tributary to W. Prong, Little Pigeon River at 1100 m)
Group 7.	Ramsay Prong above 1020 m Walker Prong above 1350 m
Group 8.	Abrams Creek at Abrams Creek Ranger Station
Group 9.	Tabcat Creek upstream from Chilhowee Lake
Group 10.	Beech Flats Creek at 1200 m
Group 11.	Beech Flats Creek immediately downstream from U.S. 441 (1430 m)
Group 12.	Abrams Creek immediately downstream from Cades Cove

Table 15. Mean water quality values for each cluster group

Group	Nitrate mg/l	Hardness mg/l	pH	Alkalinity mg/l	Turbidity NTU	Conductivity µmhos/cm
1	1.55	4.47	6.28	2.75	0.63	10.86
2	0.79	5.00	6.56	4.41	4.46	10.44
3	1.11	2.83	6.27	2.13	0.72	7.60
4	2.66	6.25	6.32	3.29	0.61	14.38
5	3.60	7.45	6.14	1.47	0.35	15.29
6	3.76	4.97	5.67	1.04	0.53	12.19
7	5.06	4.59	4.96	0.18	0.46	14.83
8	0.81	20.32	7.12	19.48	2.52	29.67
9	0.55	13.33	6.83	11.75	1.11	23.25
10	3.07	13.00	5.72	1.05	0.58	27.75
11	3.84	21.33	5.07	0.65	0.68	46.88
12	1.80	52.68	7.32	48.59	2.02	69.69

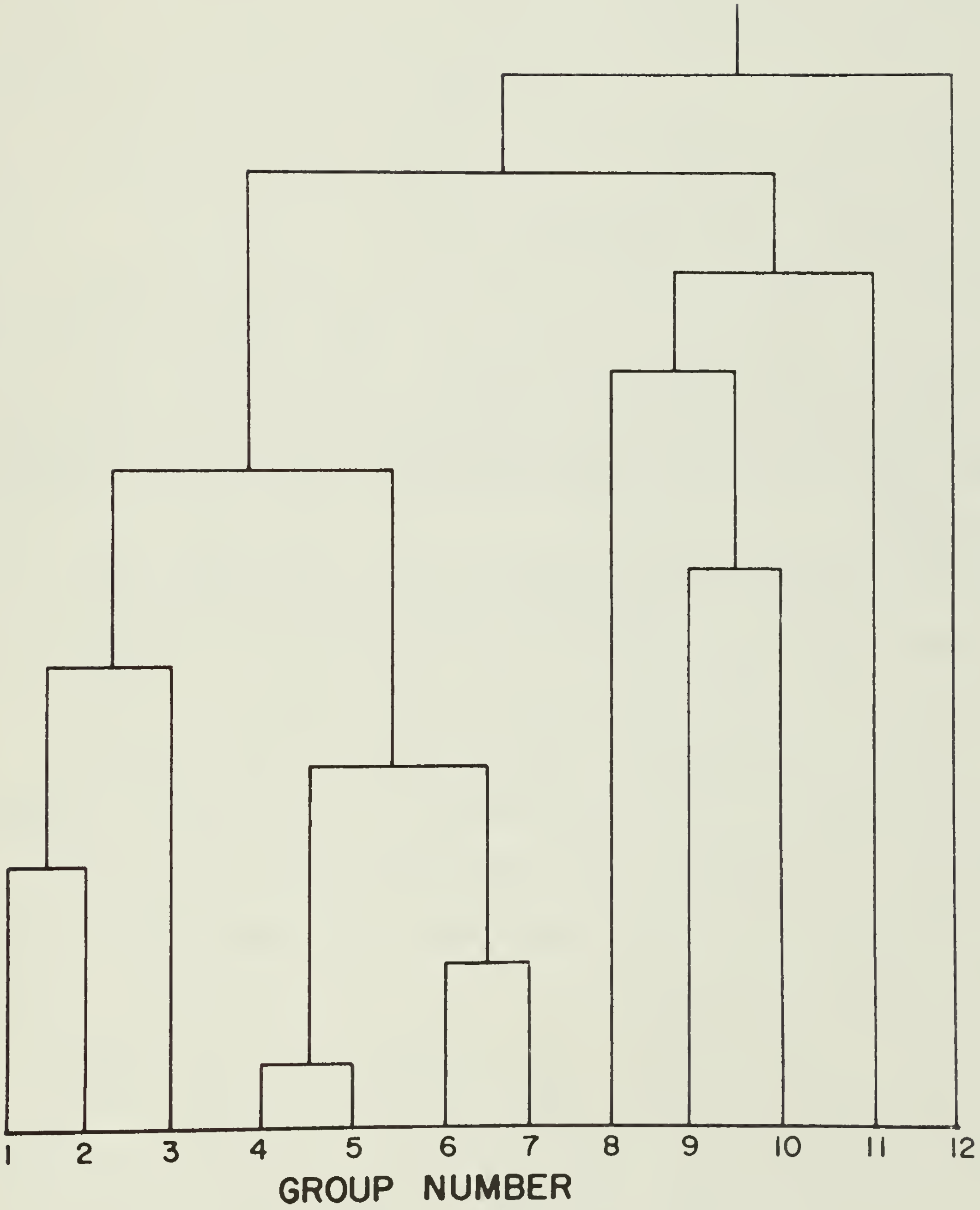

Figure 12. Cluster map showing the relative similarity of the 12 groups described in Tables 14 and 15.

watershed on Snowbird group bedrock, giving intermediate values of all parameters.

Group 2 contained only 1 stream, Mill Creek above its confluence with Abrams Creek at the bottom of Cades Cove. This stream was similar to those in Group 1 except for an extremely high turbidity value (4.5). This value was due to an extremely high reading on one occasion and is probably not representative of normal conditions in Mill Creek. For practical purposes, this creek should probably be in Group 1.

Group 3 consisted of fairly low elevation stations on the North Carolina side of the park and Panther Creek. These streams were fairly low in nitrate and extremely low in hardness and conductivity. Bedrock is almost exclusively of the Great Smoky group, and the watersheds were mostly logged.

Group 4 consisted of low elevation stations on the Middle and West Prongs of the Little Pigeon River, Beech Flats Creek above the parking area on U.S. 441, and a high elevation station on Big Creek. These streams are fairly high in nitrate, hardness, and conductivity, and somewhat low in pH. The high elevation of the two streams in logged areas has a similar effect to the virgin forest and Anakeesta bedrock on the watersheds of the Little Pigeon River, increasing nitrate concentrations and lowering pH.

Group 5 contains only main stream stations on the West Prong of the Little Pigeon River between 510 and 1275 m in elevation. Nitrate, hardness, and conductivity values are quite high, turbidity is quite low, and pH and alkalinity are not yet at the extremely low values they reach at the headwaters of the creek.

Group 6 contains four stations on the Middle Prong of the Little Pigeon River in the middle elevations and two middle elevation tributaries to the West Prong. These streams are similar to those in Group 5 but with somewhat lower hardness, conductivity, alkalinity, and pH and somewhat higher turbidity.

Group 7 contains the highest elevation stations on the Middle and West Prongs of the Little Pigeon River, with extremely high nitrate values and low pH and alkalinity, reflecting the high elevation virgin forest and Anakeesta bedrock.

Groups 8 to 12 contain only one stream each: Tabcat Creek, with its strong influence from Walden Creek group bedrock; two stations on Abrams Creek, with varying degrees of limestone influence, and two stations on Beech Flats Creek below U.S. 441, with different degrees of influence from the Anakeesta roadfill there.

Discussion

Figure 12 shows the order in which these groups are combined, most similar groups being combined first. First to be grouped together are Groups 4 and 5 and Groups 6 and 7, all primarily on the two prongs of the Little Pigeon River. Then Mill Creek (Group 2) is combined with Group 1, and the remaining groups of Little Pigeon River stations are combined.

This leaves eight remaining groups, five of which are represented by single stations. Of the three groups containing more than one station, the first is composed mainly of virgin watersheds with a few high elevation stations in logged areas; the second, of low to medium elevation logged areas primarily underlain by rocks of the Great Smoky group; and the third, of large streams in the Waldens Creek or Snowbird group bedrock. These three groups represent the vast majority of streams in the park.

BACTERIOLOGICAL WATER QUALITY

Results

All statistics calculated for bacterial densities were computed using log transformed data. Several significant correlations were found between bacteria densities and other water quality parameters, particularly temperature (Table 16). Numbers of bacteria were significantly higher in summer and fall than in winter (Fig. 13). The three groups of bacteria also decreased with increasing elevation (Fig. 13). Although these trends were significant, the three groups of bacteria were highly variable in density. Abrams Creek, which is clearly not typical of park streams, is not included in this analysis. It has been treated in detail in other studies (Silsbee et al. 1976; Larson et al. 1980). Densities of the three groups of bacteria also increased dramatically when water levels rose in response to storms (Fig. 14). Diurnal sampling during stable conditions showed no consistent diurnal patterns in bacterial density.

Discussion

Densities of the three groups of bacteria were highly variable but followed general trends relating to elevation and season. Bacterial densities were consistently higher at the low elevations than high, and higher in summer than in winter. Although numbers of visitors and wildlife activity, particularly near streams, are much greater in summer and somewhat greater in the low elevations, it is unlikely that these factors are strong enough or consistent enough to account for the trends observed in this study. It is more likely that these trends are

Table 16. Correlation coefficients between bacterial concentrations (log transformed data) and other water quality parameters. (* Indicates $p < .05$)

	Fecal Coliform	Total Coliform	Fecal streptococcus
Temperature	.62*	.39*	.60*
pH	.38*	.19*	.23*
Alkalinity	.37*	.06	.07*
Hardness	.23*	-.06	-.02
Nitrate	-.36*	-.28*	-.29*
Conductivity	.13	-.11	.02
Turbidity	.37*	.25*	.26*
Fecal Coliform	--	.43*	.54*
Total Coliform	--	--	.53*

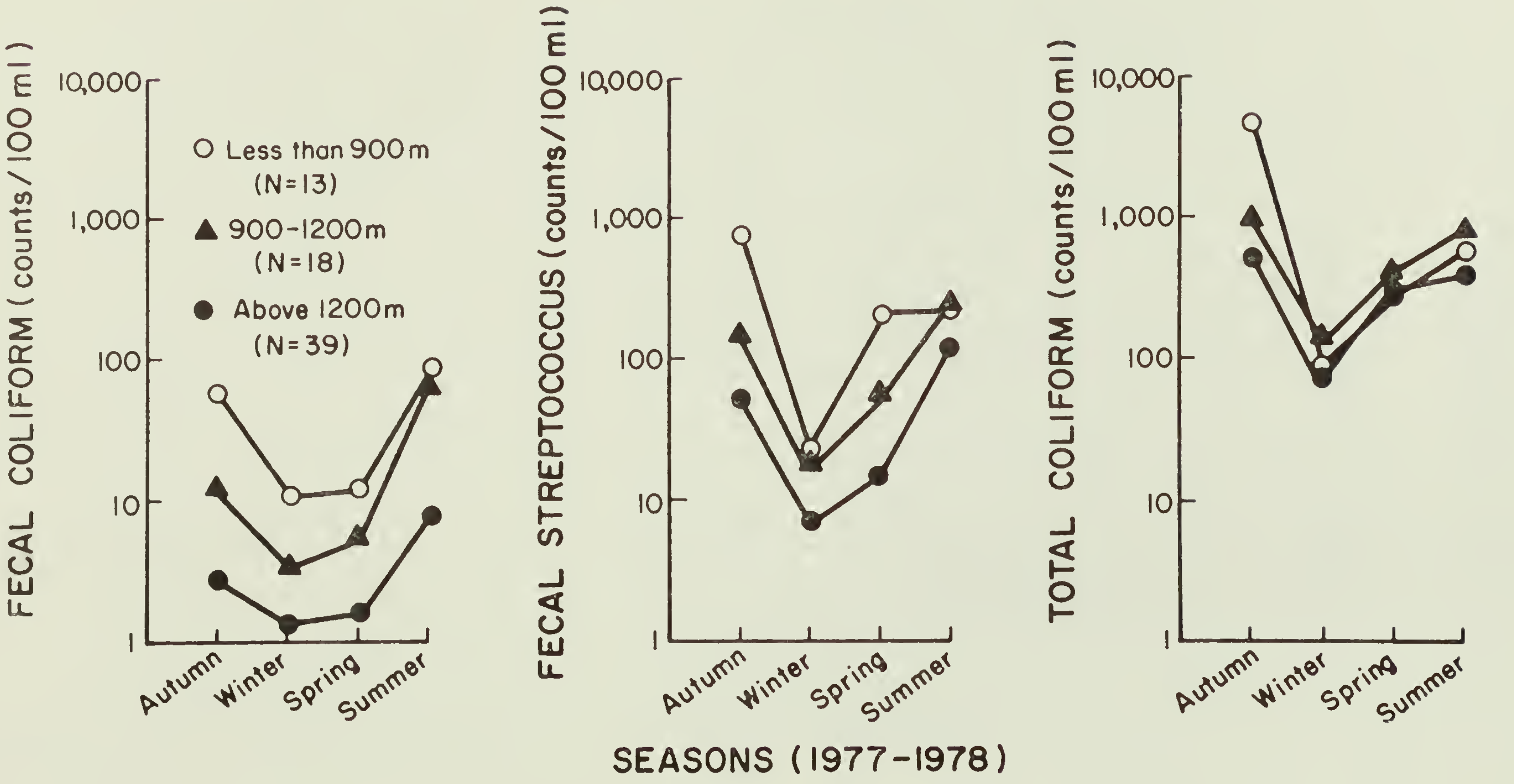

Figure 13. Seasonal patterns in bacterial densities in three elevation ranges.

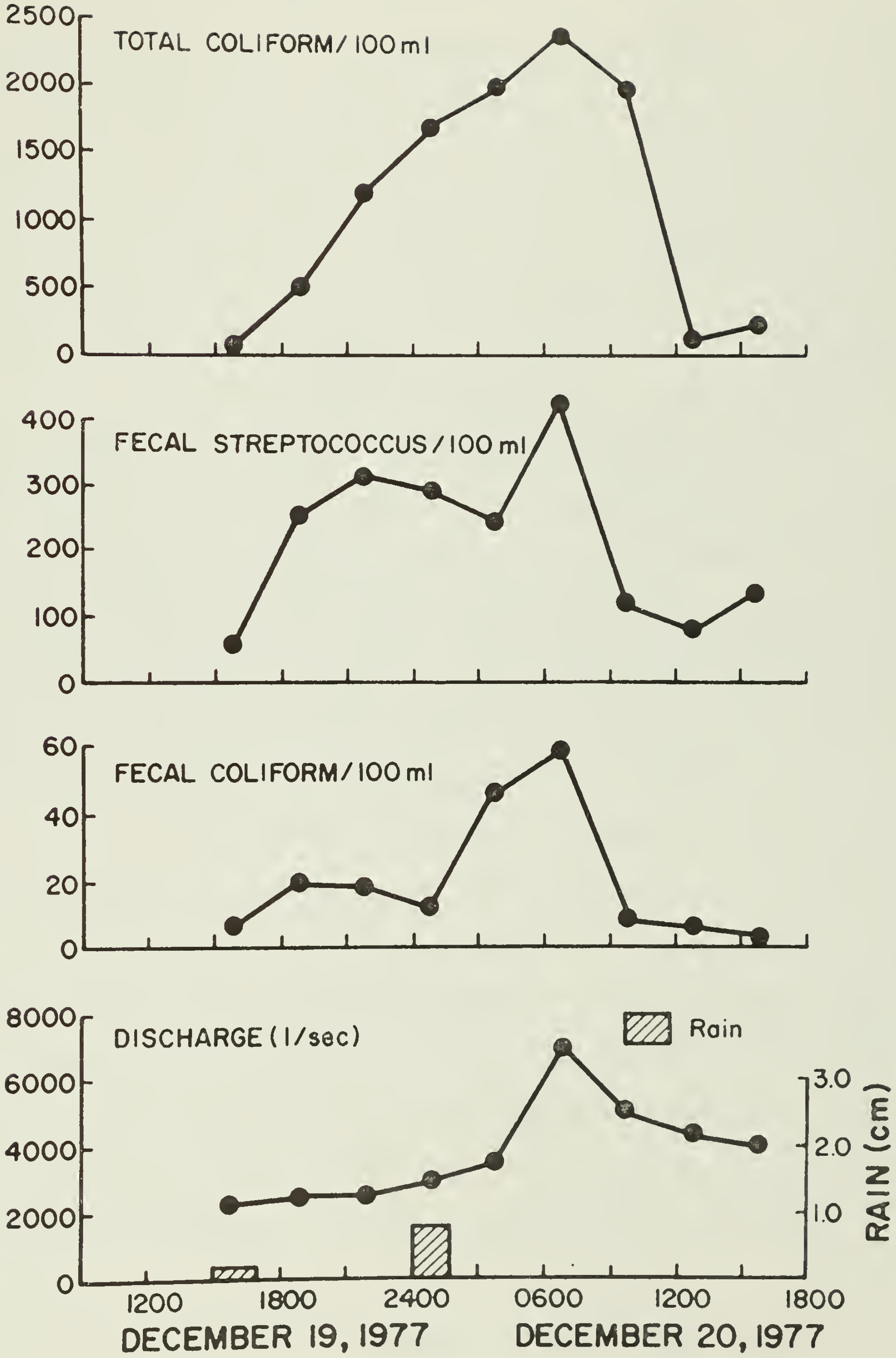

Figure 14. Bacterial densities during and following heavy rain, West Prong, Little Pigeon River, December 19-20, 1977.

a result of differences in soil and water temperature. Bacteria can survive and reproduce more successfully under warm conditions (McSwain and Swank 1977, Hendricks and Morrison 1967). Therefore, higher concentrations of bacteria would be expected in warmer soils and waters. The high correlation coefficients between water temperature and bacterial concentrations probably reflect primarily this difference in survival and reproduction of bacteria in the soil and stream sediments rather than differences in inputs of bacteria from humans or wildlife.

It should be emphasized, however, that wide fluctuations do occur around all of these average values. The occasional peak values probably represent contamination from wildlife or visitors, material washed in from the forest floor after rains, or other sudden inputs into the stream. Because of the large populations of bacteria in the forest soil and stream sediments, anything which might wash material into the stream or stir up the streambed must be considered as a possible source of sudden peaks in bacterial densities. McSwain and Swank (1977) observed increases in bacterial densities downstream from large concentrations of swimmers, which they attributed to stirring up the bottom sediments by the swimmers. They also observed significant diurnal fluctuations where no swimmers were present. Diel sampling in the present study showed tremendous increases in bacterial densities following storms, presumably due to flushing of forest floor bacteria into the stream. Clearly, all increases in bacterial densities cannot be automatically attributed to contamination from humans or wildlife.

Since the large number of samples being processed did not permit time to prepare different dilutions of each sample, peak concentrations could only be reported as "too high to count". These high counts appeared from time to time in a wide variety of circumstances. Furthermore, there did not appear to be any consistent relationship between bacterial numbers and visitor use of Park Service developments, including backcountry trails and campsites and front country campgrounds, picnic areas, and roads. Since contamination appears to be of such an intermittent nature, any study aimed at determining levels of contamination from any particular source would do better to look at the frequency of occurrence of peak values rather than at general background levels of bacteria. Unfortunately, this would require intensive sampling and consequently a substantial commitment of time and effort.

The results of this study suggest that bacterial contamination of streams in areas of visitor use does not generally occur in quantities that are unusual for remote areas of the park.

SPECIAL PROBLEMS

Potential Effects of Acid Precipitation

The degree to which acid precipitation will affect aquatic systems depends not only on the pH of the precipitation but also on the inherent ability of the system to resist changes in pH. The mountains of Western North Carolina and East Tennessee, in general, are a highly susceptible region because of already acidic soils and low buffering capacity (Klopatek et al. 1980).

The potential impacts of reduced pH on fish and salamander populations as well as other aquatic life are unquestionably great (Beamish 1976). In addition, recent studies have shown the pH of rain in the vicinity of the Smoky Mountains to be decreasing quite substantially (Larson et al. 1978). Rain samples collected in association with this study had an average pH of 4.15, with a minimum of 3.5. Data from this study show a decrease in stream pH following rainstorms, although it is not clear to what degree this is a result of the acidity of the rain (Fig. 15).

Data from this study, while not able to demonstrate effects of acid precipitation, do give an indication of the potential of different streams to be affected. Alkalinity is a measure of the amount of acid which must be added to a given volume of water to decrease the pH to 4.7. It is therefore a fairly good indication of how susceptible the stream is to inputs of acid. It should be remembered, however, that it is primarily the buffering capacity of the soil which will determine the susceptibility of the stream. The alkalinity of the stream is only an indicator of what buffering is probably present in the soil.

The pH values measured in this study ranged from 4.4 to 7.9, and alkalinity, from 0 to 78.0. The major influences on these parameters were geology and elevation. Clearly then, there is a wide range of potential impacts on park streams, depending largely on elevation and geological substrate.

The effect of acid rain on a stream, though, depends not only on the capacity of the acid to depress the stream pH, but also on the degree of pH depression which would be necessary to damage biological components of the stream ecosystem. Detectable effects on aquatic organisms have been observed at pH levels of nearly 6 (Wright et al. 1976; Sutcliffe et al. 1973). Clearly, a stream with a pH 7.5 would have to undergo considerable acidification before major impacts would be expected. A stream with a pH of 5.9, however, might only need a small change in pH

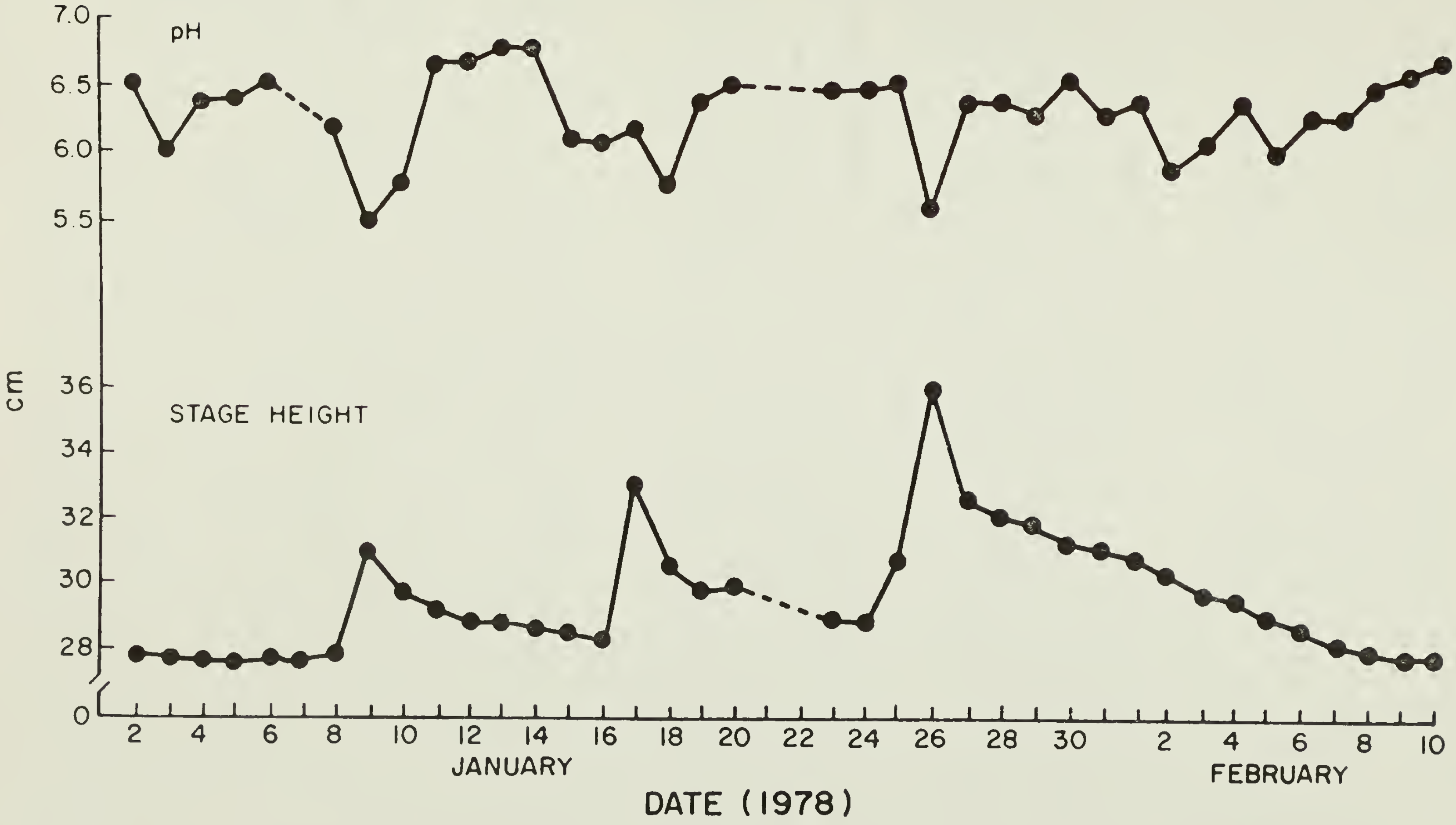

Figure 15. Daily stage height and pH of Scratch Britches Creek, January 2 to February 10, 1978.

to affect stream biota. On the other hand, a stream which already had a pH of 4.5 due to Anakeesta drainage would probably not be significantly affected since only extremely acid-tolerant species would be present and large inputs of acid would be necessary to significantly affect pH. It is probably the streams with intermediate pH values, between 5.0 and 6.0, and low alkalinities, therefore, which are most susceptible to the effects of acid rain.

The most sensitive streams within the park are primarily in the higher elevations, particularly in areas underlain by Great Smoky group bedrock or with limited quantities of Anakeesta. Areas underlain almost entirely by Anakeesta already have high acid inputs, and the additional input from the rain would probably have little additional effect on pH. Low elevation areas and areas with Walden Creek group or Snowbird group bedrock generally have somewhat higher pH values and alkalinity and would be more resistant to the effects of acid precipitation. Areas with significant quantities of limestone are extremely well buffered and would show little or no effect.

Although the most poorly buffered streams represent a fairly small proportion of the total miles of streams in the park, they are highly significant in many ways. Because of the high elevation, different climate, different vegetation, and different stream chemistry, they are presumably quite different biologically from the lower elevation streams. Although little work has been done on aquatic invertebrates or plants in the park, it is reasonable to assume that there are species in the higher elevations which are not seen lower down in the park. In addition, many higher elevation streams harbor remnant populations of native brook trout, which could be affected by acidification of the streams.

Although the very low alkalinity, high elevation streams are probably most susceptible to acid precipitation, it is only a very small number of streams in the park which have sufficient alkalinity to be considered well protected. Because of the large fluctuations in stream pH observed in this study, particularly following storms, and because brief but sudden depressions in pH may be as harmful as long-term gradual declines, close monitoring of pH levels in both extremely low alkalinity and intermediate alkalinity streams is necessary in order to determine what effect acid precipitation may actually be having on the resources of the park.

Impact of Cades Cove on Water Quality of Abrams Creek

The Cades Cove area was specifically avoided in this study because so much work has been done there in the past (Mathews 1978, Kelly 1974, Silsbee 1976). Samples were taken above and below Cades Cove on Abrams Creek, however. Those analyzed for Ca, Mg, Na, K, and Si emphasized the importance of the limestone substrate in changing the water quality of Abrams Creek as it flows through the Cove. Ca and Mg concentrations increased severalfold as Abrams Creek passed through the Cove, while Na, K, and Si increased only slightly (Table 17). Since Ca and Mg are easily dissolved from limestone, this suggests that most of the increase in conductivity, hardness, and alkalinity is due to the influence of the limestone. If greatly increased erosion of the sandstone-derived overburden were responsible, as has been suggested in the past (Mathews 1978), all five elements would have increased nearly in the same proportions they occurred in the upstream sample.

Table 17. Concentration of elements in water of Abrams Creek.

Location	Ca	Mg	Na	K	Si
Above Cades Cove	1.01	.32	1.00	.70	3.45
Above Mill Creek	26.07	3.46	1.36	.81	4.52

The Effect of the Roadfill on U.S. 441 on Beech Flats Creek

The changes in Beech Flats Creek as it passes through roadfill under U.S. 441 have been well documented in other studies (Herrmann et al. 1976; Huckabee et al. 1975). In this study, samples were taken regularly above and below the marking area. Results are in Table 18. Alkalinity and pH are greatly depressed as the stream crosses the road, and conductivity, hardness, Ca, and Mg greatly increase. Cobalt, manganese, aluminum, and zinc are also present in significant quantities below the park area, representing leachate from the Anakeesta.

A comparison was also made between the impact of the Anakeesta roadfill on Beech Flats Creek and the natural Anakeesta drainage on Walker Prong. Walker Prong, although it shows lower pH and alkalinity than Beech Flats, does not have the high conductivity and high metal concentrations that are present in Beech Flats Creek.

The freshly exposed surfaces of the crushed rock in the roadfill have not had the long period of time to weather that rock in the natural situation has had. Consequently, the metals present in the rock have not had time to be extensively leached. Even though the leachate is much more concentrated in the case of Beech Flats Creek, the pH is not lower because it is somewhat buffered by leaching of the metals.

Table 18. A comparison of water quality in Beech Flats Creek above and below U.S. 441 and Walker Prong above U.S. 441

Parameter [1]	Beech Flats upstream from U.S. 441	Beech Flats downstream from U.S. 441	Walker Prong upstream from U.S. 441
pH	6.45	4.73	4.60
Conductivity	15	53	15
Alkalinity	3.7	0.1	0.0
Hardness	6.3	27.0	5.3
Ca	1.79	5.08	0.96
Mg	0.61	3.27	0.57
Na	1.18	1.13	0.41
K	0.62	0.77	0.53
Si	4.16	3.79	2.26
Co	N.D.[2]	.012	N.D.
Mn	N.D.	1.51	N.D.
Zn	N.D.	.099	N.D.
Al	N.D.	2.11	N.D.

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[1] Sample sizes: One for cations; pH, conductivity, alkalinity, and hardness are 5 for each Beech Flats site and 12 for the Walker Prong site.

[2] Not detected.

Effects of Fire

Other studies have shown high losses of nutrients from soils following fires (Christensen 1973, 1976). This has been attributed to increased nitrification, increased susceptibility to soil erosion, and decreased uptake by vegetation.

In this study, no intensive work was done on burned sites, but a few samples were taken from small streams draining Turkey Knob, east of Cosby. The area was burned in a small fire on April 10, 1978, and samples were taken on April 14. The streams were dry for a long period following this, preventing resampling, but one sample was taken again on August 10. Results are shown in Table 19.

Since no samples were taken before the fire for comparison, it is difficult to draw to draw any conclusions from these samples. Nevertheless, nitrate concentrations were extremely high for an area of such low elevation, particularly in the summer sample. Conductivity and hardness were also higher than would be expected in such an area. This suggests that some loss of nutrients into the streams occurs when the forests of the Great Smoky Mountains are burned. Much more data is necessary to confirm this, however.

DESCRIPTION OF INDIVIDUAL WATERSHEDS

The following descriptions give a brief summary of the geology and logging history of each watershed. The amount of sampling conducted on each watershed is also described. Water quality of each watershed is not described in detail, however, as this would be too cumbersome. For this, the reader is referred to the descriptions of the effects of geology and logging on water quality or to the raw data. Geological descriptions

Table 19. Water quality of streams draining the burned area on Turkey Knob.

Parameter	East side 4/14/78	West side 4/14/78	East side 8/10/78
pH	6.5	6.5	6.8
Conductivity	10	18	23
Turbidity	.80	.78	2.0
Alkalinity	6.8	3.6	7.0
Acidity	4.6	5.0	7.8
Hardness	6.8	9.2	10.6
Nitrate	2.0	3.1	6.2

are based on King et al. (1968); logging history on Lambert (1958).

(1) Cosby Creek - Most of the Cosby Creek watershed is underlain by Thunderhead sandstones of the Great Smoky group, although the lower portions of the watershed are underlain by rocks of the Snowbird group. Large scale commercial logging was never done in the Cosby area, but most of the lower slopes (below 780 m in elevation) of the mountains were farmed, and selective cutting of the more valuable trees certainly occurred further up the slopes.

Sampling in this study was limited to seasonal samples from the base of Cosby Creek and a few samples from Crying Creek, Rock Creek, and Cosby Creek above the campground. A water quality monitoring station is currently operating at the base of Camel Hump Creek, and much data is available from this location.

(2) Indian Camp Creek - Indian Camp Creek is similar to Cosby Creek in geology and forest cover. The only samples taken in this study were seasonal samples from the base of Dunn Creek.

(3) Webb Creek - No sampling was done on the Webb Creek watershed, but it is similar in geology and vegetation to the Cosby and Dunn Creek areas, so water quality would be expected to be similar.

(4) Middle Prong, Little Pigeon River - Except for the agricultural areas near the base of this watershed, it is mostly virgin forest, although selective cutting did occur higher in the watershed, and some areas in the uppermost parts of the watershed burned in fires which escaped from logging operations on the North Carolina side of the park. The bedrock of the area is mostly of the Great Smoky group, but there are areas of

Anakeesta formation in the uppermost parts of the watershed, and of the Snowbird group in the lower parts.

Extensive sampling was done within this watershed, including seasonal gradient sampling along the trail to Ramsay Cascades and above the cascades, 24-hour diel studies above Porters Creek and on Porters Creek, seasonal samples of several tributary streams, and occasional additional samples at the park boundary.

(5) Dudley Creek - This watershed includes much low elevation, previously farmed land and also virgin forests on the very highest slopes of Mount LeConte. Much of the watershed is underlain by rocks of the Walden Creek group, but Thunderhead sandstone and Anakeesta formation are present in the higher elevations.

Except for a few spot samples on Little Dudley Creek, sampling was limited to the daily stations on Scratch Britches and LeConte Creeks (24-hour diel studies were also conducted at these stations). The differences observed between these two streams is typical of the difference between the high-elevation, virgin forest and Anakeesta or Thunderhead bedrock found high on Mount LeConte and the low elevation former fields and Snowbird group rocks found in the lower part of the watershed.

(6) West Prong, Little Pigeon River - This watershed is similar to the Middle Prong, having only selective cutting with much virgin forest left and Anakeesta bedrock in the upper elevations and old farmland in the low elevations, although more farmland is present in the West Prong.

Extensive sampling was done in this watershed, with seasonal gradients up as far as the river follows the road, 24-hour diel samples at the park boundary, and occasional additional spot samples, both at the park boundary and at several locations farther up the watershed.

(7) Little River - This watershed was almost entirely logged between 1900 and 1926. It is underlain by rocks of the Great Smoky group with some Anakeesta present down to a point slightly above Metcalf Bottoms, where it crosses the Greenbriar Fault onto bedrock of the Snowbird group.

Sampling on this watershed included seasonal gradients from Collins Gap to the park boundary (only as high as the end of the trail in winter) and additional spot samples at the park boundary and at Elkmont.

A water quality monitoring station is now present on Huskey Branch, but data from that station was not included in this study.

(8) The Middle Prong of the Little River is similar to the main branch (East Prong) above Elkmont, although logging was not finished until 1939. Spot samples were only taken from the base of the stream.

(9) The West Prong of the Little River is underlain primarily by Snowbird bedrock and is almost entirely logged. It is also generally lower in elevation than watersheds 1 to 8.

(10) Hesse Creek was not sampled in this study. It is low in elevation and underlain by bedrock of the Snowbird and Walden Creek groups and is probably similar to Tabcat Creek in water quality.

(11) Abrams Creek is quite unique in the park. Above Cades Cove it is similar to other streams draining the north side of the park. It is largely underlain by rocks of the Great Smoky group and predominantly unlogged. Entering Cades Cove, it flows through both a large agricultural area and the largest area of limestone in the park. After passing through the Cove, it continues through low elevation mostly

unlogged forests and rocks of the Snowbird and Walden Creek groups.

Sampling in this study was limited to occasional samples above and below Cades Cove and at the Abrams Creek Ranger Station. Abrams Creek has been treated in detail in other studies (Mathews 1978; Silsbee et al. 1976), so it was not deemed necessary to spend large amounts of time on it in this study. Data collected in this study emphasize the importance of the limestone in Cades Cove as an influence alongside that of historical management in affecting water quality.

(12) The Panther Creek watershed is quite low elevation. It begins in areas of Great Smoky group bedrock, flowing through Snowbird group areas and finally Waldens Creek group. Much of the forest was never logged, but there are areas of old farmland. Because of the low elevations, the area is much dryer than the forests of the higher mountains. Fires have also been quite common in the western part of the park, possibly having similar effects to logging. Although this stream was designated as a gradient stream, difficulty of access resulted in gradient samples only being taken once. Samples at Parsons Branch Road and just above Chilhowee Lake were taken seasonally, however.

(13) Tabcat Creek is almost entirely Waldens Creek group bedrock. It is quite low elevation and the forests are similar to those of Panther Creek. Seasonal samples were taken just above Chilhowee Lake.

(14) Parsons Branch is underlain primarily by rocks of the Great Smoky group. It is fairly low in elevation and no extensive logging occurred on the watershed, but much of it was settled. Sampling was limited to seasonal samples where it first crosses Parsons Branch Road, and at

the park boundary.

(15) Twenty-Mile Creek drains the area of the park which has not been mapped geologically, but it was assumed to be primarily the Great Smoky group. The watershed was logged almost all the way to the top, but less valuable trees were not cut. Seasonal samples were taken from the base of the creek at the park boundary.

(16) The Eagle Creek watershed is similar to Twenty-Mile Creek, although it was more thoroughly logged. It was designated as a gradient stream, but gradient sampling was only conducted twice because of the difficulty of access.

(17 and 18) Forney Creek and Hazel Creek are both in the area of the park which was not mapped geologically and were both thoroughly logged. Samples were taken twice from the base of each, and once from several stations higher up on Hazel Creek.

(19) Noland Creek is primarily on Great Smoky group rocks, with some Anakeesta also present. It was completely logged except in the higher elevations. Seasonal gradient sampling was conducted as well as two 24-hour diel studies.

(20) Deep Creek is almost entirely on Great Smoky group bedrock, although some Anakeesta is also present. There is a small area of basement complex right at the base of the watershed. Logging occurred in the lower elevations but did not reach the heads of Deep Creek or its major tributaries. Sampling was limited to seasonal samples at the park boundary.

(21) Cooper Creek is underlain mainly by Thunderhead sandstone. It also has some basement complex bedrock in the lower elevations. It is a quite low elevation watershed, not reaching all the way up to the state line. It was almost completely logged or farmed. No samples were taken on this watershed, but water quality is probably similar to that in the lower elevations of neighboring watersheds.

(22) The Oconaluftee River watershed contains bedrock from four of the six geological groups. Most of the watershed is Great Smoky group, but Anakeesta, basement complex, and Snowbird group are also present. Water quality at the top of the river is dominated by the Anakeesta roadfill on U.S. 441. Logging on this watershed was patchy, some areas being thoroughly clearcut and burned, others relatively untouched. Gradient samples were taken seasonally and some additional samples were taken at the top and bottom of the stream.

(23) Bradley Fork is a major tributary to the Oconaluftee River. It has Great Smoky group, Anakeesta, and basement complex bedrock, with Thunderhead sandstone predominating. Logging was less extensive on Bradley Fork than the Oconaluftee River, and much of it is still covered with virgin forests. Seasonal samples were taken just above Smokemont campground.

(24) Raven Fork has Great Smoky group, Snowbird group, and basement complex bedrock, with Great Smoky group and basement complex covering most of the watershed. Some logging occurred here, but much of the watershed is virgin. Seasonal samples were taken above the Oconaluftee River, and one sample was taken above the Indian Reservation.

(25) Straight Fork is quite similar to Raven Fork, although it has more Snowbird group bedrock and is somewhat smaller and lower in elevation. It was only sampled once, at the Indian Reservation boundary.

(26) Bunches Creek is almost entirely on Great Smoky group bedrock. Most of the watershed was logged. It was only sampled once, at the Indian Reservation boundary.

(27) Cataloochee Creek has varied geology, including several formations of the Snowbird group, basement complex, and Thunderhead sandstone. Much of the watershed was logged, but there are also substantial areas of virgin forest. This was a gradient stream, but seasonal samples were only taken as far up as the base of Pretty Hollow Creek.

(28) Big Creek is underlain by Thunderhead sandstone in the higher elevations and Snowbird group rocks near the park boundary. It was one of the first watersheds in the park to be heavily logged, and almost the entire watershed was cut. Big Creek was a seasonal gradient stream, and diel samples were also conducted.

SUMMARY

(1) Elevation has a significant influence on water quality. The higher rainfall and lower evapotranspiration of the high elevations results in lower retention times for the groundwater. Consequently, geologically derived elements are in lower concentrations, and pH is lower in the high elevations than low. Elevation also influences nitrate levels and turbidity, but the mechanisms for this are not clear.

(2) Geology has a significant effect on pH, alkalinity, conductivity, hardness, and concentrations of Na, K, Ca, Mg, and Si. Differences between geological types are related to the mineral composition of the bedrock and its relative resistance to weathering.

(3) Nitrate concentrations are higher in areas of virgin forest than those which were logged before the park was established. This is probably related to accumulation of nutrients in the second growth forest.

(4) Seasonal patterns in water quality are related to differences in temperature, water level, and forest growth and decomposition cycles.

(5) Water quality of streams was changed by storms because storm runoff entered the streams rapidly through the upper layers of the soil and forest floor rather than after long contact with the soil and bedrock.

(6) Bacterial densities appear to be controlled largely by water temperature. Bacteria survive and multiply more successfully under warm conditions, producing higher densities in the low elevations than high, and higher densities in summer than winter. Densities also increased markedly after storms, due to the washing in of material from the forest floor.

(7) Stream substrate was dominated more by larger size classes where stream gradient was high and smaller size classes where gradient was low, due to the ability of the stream to move larger material where gradient is higher.

(8) More large woody debris was present in virgin areas, due to the lack of mature trees in the second growth forest.

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